Waste Infrastructure Technology Mix - Ricardo

NATIONAL INFRASTRUCTURE COMMISSION
Better infrastructure for all

October 2023

Foreword and update from the National Infrastructure Commission

In January 2023, the National Infrastructure Commission commissioned external consultants Ricardo Energy & Environment (Ricardo) to complete analysis and modelling on waste arisings and waste treatment methods in England. This looked at both the mix and capacity of waste infrastructure required now and in a range of potential future scenarios out to 2055. Ricardo completed its modelling in the summer.

In July, government announced that energy from waste (EfW) would be included in the Emissions Trading Scheme (ETS) from 2028. This will impact on the gate fees that EfW operators charge to anyone using these facilities, including local authorities. Due to the timing of the announcement, this consideration was not included in Ricardo's modelling for the Commission. Therefore, the Commission has undertaken its own modelling of gate fees, building on Ricardo's work and taking the government announcement and other evidence into account. This additional modelling is outlined below and should be read in conjunction with Ricardo's Waste Infrastructure Technology Mix report.

Methodology for estimating gate fees

The Commission's estimates of EfW gate fees – which are the fees charged for a range of waste treatment, recovery and disposal options – rely on WRAP's 2021/22 gate fees report, and are aligned with their recent 2022/23 estimates.[1] All prices have been adjusted to 2022 prices using Office for Budget Responsibility inflation forecasts. The analysis then estimates the additional cost of adding EfW to the ETS and implementing carbon capture and storage (CCS) onto EfW plants. Gate fees for all other facility types are assumed to remain constant in real terms.

Energy from waste gate fee under the emissions trading scheme

EfW is set to join the ETS in 2028, which could have an impact on their gate fees. Under the current ETS proposals, facilities will be required to acquire an emissions allowance to cover the incineration of fossil materials at EfW facilities. Incineration of biogenic material would be excluded. The Commission assumes mixed black bag waste treated at these facilities contains 50 per cent biogenic carbon and 50 per cent fossil carbon, consistent with government analysis in the consultation for including EfW and incineration in the ETS.[2] Future demand for EfW capacity and emissions estimates provided by Ricardo are used to estimate gate fees.

Gate fees for unabated energy from waste facilities

EfW facilities without CCS will need to buy credits for their fossil emissions. This would present an additional cost that can be expected to increase gate fees. The additional cost is calculated by applying government's schedule of carbon prices[3] to Ricardo's estimates for annual EfW fossil emissions, which is then transformed into a cost per tonne of waste treated through EfW facilities. Estimates of EfW gate fees from WRAP are increased accordingly and are presented in **Table A.1**.[4]

Gate fees for abated energy from waste facilities

Commission analysis assumes CCS to be a simple additional cost to existing EfW gate fees, while revenues associated with negative emissions generated by capturing biogenic carbon are netted off the gate fee. Ricardo's analysis includes estimates for the annuitised capital cost of CCS infrastructure and its annual operational expenditure when attached to an EfW facility.[5] Both operational expenditure and additional annuitised capital cost of CCS were added directly to estimated gate fees from WRAP.

Under the ETS, EfW+CCS facilities may sell any credits they generate by capturing emissions from biogenic waste. The number of credits is calculated based on the quantity of biogenic emissions produced through combustion, less any that escape because the carbon capture technology is imperfect. The credits generated in each year are then valued using government's schedule of carbon prices, and divided by the number of tonnes of waste treated through CCS enabled facilities.

Estimated costs are presented in **Table A.1**. The median landfill gate fee is taken from WRAP's 2022/23 gate fees report. It excludes landfill tax, currently set at £98.60/tonne for 2022/23 across all nations.

Table A.1: Estimated gate fees by treatment method (£, 2022 prices)

Technology (all include transport)	2030
Landfill (excluding landfill tax)	28
MRF	80
Abated EfW	130
Unabated EfW	175

Note: EfW gate fees under the ETS will vary over time depending on carbon prices. This table provides a snapshot of 2030 gate fee estimates in 2022 real prices.

Uncertainties and limitations

This analysis has been designed to be proportionate to the level of detail the Commission has proposed in the recommendations.

Estimated gate fees are subject to assumptions and demonstrate the potential way gate fees might evolve for the EfW sector as a result of proposed government plans and subsequent recommendations. The Commission makes assumptions on emissions content and gate fees, as well as forecasts from Ricardo on how waste tonnages and emissions from these plants might evolve on the path to net zero.[6]

For estimated abated EfW gate fees, the Commission recognises that these values may be underestimated, as the gate fee does not incorporate the cost of transportation and storage for carbon. There is limited evidence to suggest the scale of this cost to EfW plants to date, due to the novelty of CCS technology. However, it is likely to further raise the cost of EfW+CCS. Important cost drivers may be source-sink distance and economies of scale, and any industrial CCS projects will likely need to share transport and storage capacity with each other and power sources – creating challenges and opportunities, particularly around the development of clusters or hubs.[7]

References

1 WRAP (2022, 2023), **Gate Fees reports**

2 HM Government (2022), **Developing the UK Emissions Trading Scheme (UK ETS)**

3 Department of Energy Security and Net Zero (2023), **Green Book supplementary guidance: valuation of energy use and greenhouse gas emissions for appraisal**

4 WRAP (2022), **Comparing the costs of alternative waste treatment options**

5 Annuity values portray the cost of capital spend over time

6 Ricardo Energy & Environment (2023), **Waste Infrastructure Technology Mix Report**. This analysis maps out the mix of waste infrastructure technologies and capacities needed to get the waste sector to net zero by 2050 and reduce other environmental impacts.

7 Element Energy (2013), **The Costs of Carbon Capture and Storage for UK industry: A high level review**

WASTE INFRASTRUCTURE TECHNOLOGY MIX REPORT

Research and Modelling to Support the Second National Infrastructure Assessment: Understanding the Waste Sector's Contribution to Net Zero Targets and the Transition to a Circular Economy

Report for: National Infrastructure Commission

Ricardo ref. ED17443 Issue: Final 22nd August 2023

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Ricardo is certified to ISO9001, ISO14001, ISO27001 and ISO45001.

EXECUTIVE SUMMARY

The National Infrastructure Commission (the Commission) is working on the second National Infrastructure Assessment, to be published in autumn 2023. The assessment analyses the UK's long term economic infrastructure needs, outlining a strategic vision over the next thirty years and setting out recommendations for how identified needs should be met. This includes recommendations to the UK Government on the role of the waste sector in enabling the move towards a more circular economy.

The Commission wished to appoint a specialist Supplier to provide waste sector research and modelling capabilities to support it to develop its waste sector recommendations in the Assessment.

The research and modelling were to focus on the challenge the Commission highlighted as a priority for the waste sector in its Baseline Report, to "examine the role of the waste sector in enabling the move towards a more circular economy". The next National Infrastructure Assessment will include recommendations to government on the role of the waste sector in reaching net zero targets and moving towards a more circular economy.

Scope

Ricardo Energy & Environment (Ricardo) were commissioned to provide specialist waste sector research and modelling to support the Commission's recommendations to the UK Government. The scope of work involved the delivery of a Net Zero Pathway (NZP) and Enhanced Circularity Pathways (ECP).

The scope of the NZP was to assess the current performance of the waste sector in terms of capacity, cost, and environmental impact (carbon), and to develop and model the least cost infrastructure pathway for the waste sector to meet the sixth carbon budget by 2035 and net zero by 2050 across different arisings scenarios. This included the quantification of required infrastructure capacity, alongside its costs and benefits. The scope of this was all waste streams and sources except hazardous and nuclear waste.

For the ECPs, the scope was to gather evidence to identify waste streams with the greatest a) negative environmental impact of extraction and processing and b) potential for circularity. This involved modelling the capacity and mix of infrastructure, otherwise known as enhanced circularity pathways, required to deliver different circularity targets for each waste stream. This assessment also included the development of a cost-effectiveness metric for each target related to greatest avoided environmental damage per pound spent, allowing the Commission to determine the preferred circularity target for each identified waste stream. This circularity target for each waste stream was then fed back into each net zero pathway from workstream 1 to determine an overall level of circularity.

NZP Modelled Scenarios

To develop the NZPs, we developed four different future scenarios. These consist of two scenarios focusing on future potential waste arisings, and two scenarios also factoring in differences in waste composition of food, plastics, paper and card. The four scenarios modelled are:

1. Scenario 1: High Arisings
2. Scenario 2: Low Arisings
3. Scenario 3: High Arisings + High Composition
4. Scenario 4: Low Arisings + Low Composition

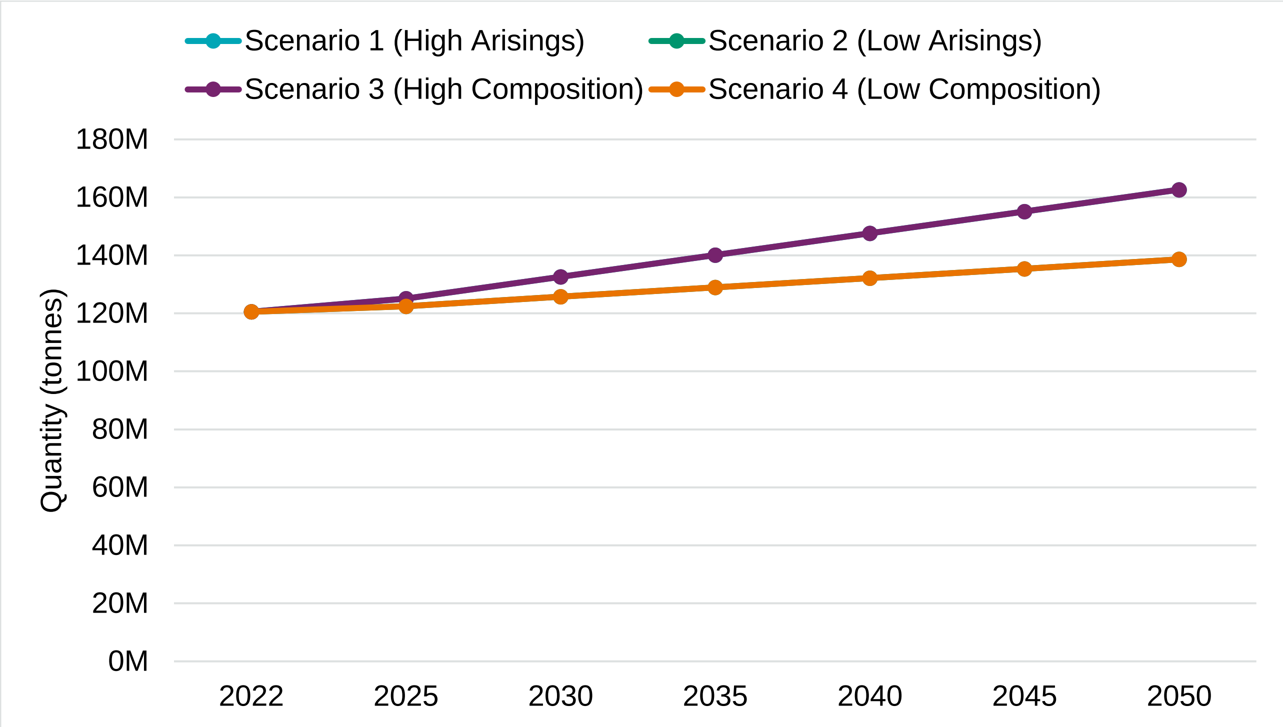
For each of the four scenarios identified above, we used the NZP model to calculate how the following variables change from the baseline year (2022) to 2055:

1. Carbon emissions (CO2e)
2. Costs
3. Recycling rate

Net Zero Pathway Results

In 2050 it is expected that the total tonnage of waste in England will rise from the baseline year tonnage of 120Mt to approximately 170Mt in the high scenarios 1 and 3, and 140Mt in scenarios 2 and 4. Therefore, even under the low arising scenario assumptions, in 2050, an approximate additional 20MT of waste will need managing in England (a 15% increase from the baseline), as shown in Figure 1.

Figure 1: Comparison of total waste arisings by scenario

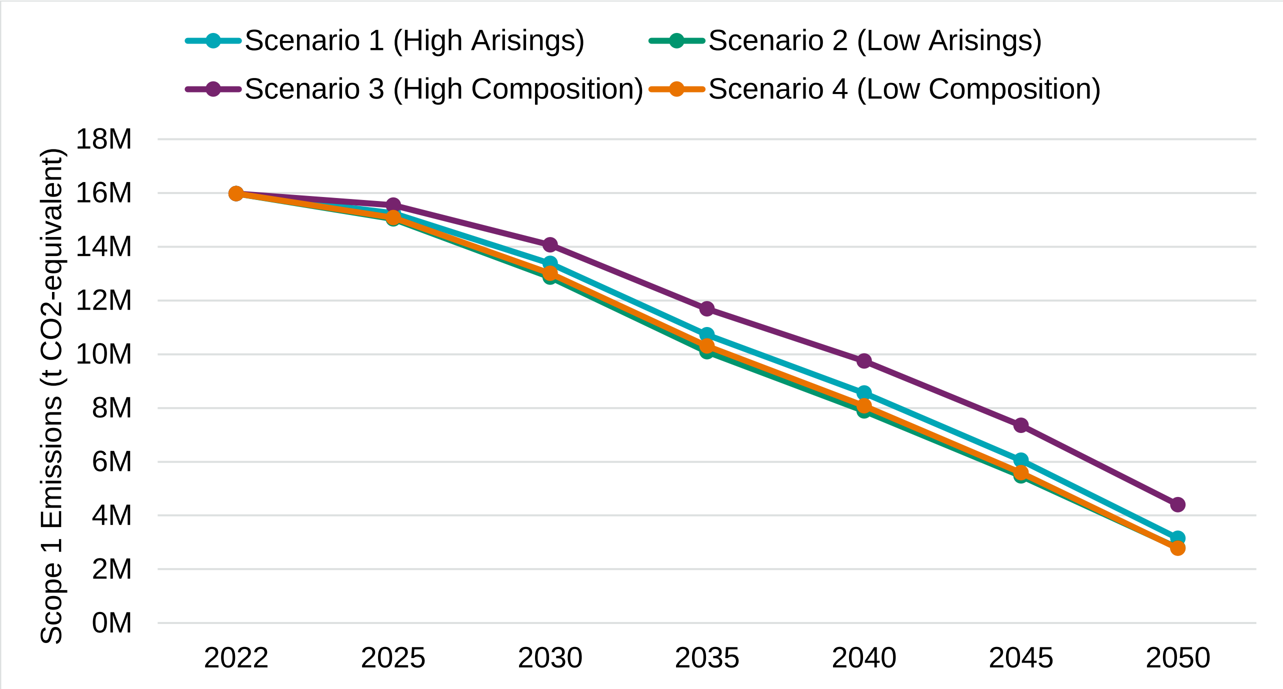


The projected tonnage is identical for scenarios 1 and 3 and for scenarios 2 and 4. This is because scenarios 1 and 3 both have high waste arisings assumptions, with scenarios 2 and 4 following low waste arisings assumptions.

Greenhouse Gas Emissions

Figure 2 displays the results of the GHG emissions (t CO_2e) modelled that result from the waste tonnages forecast from 2022 to 2050. Under the four modelled scenarios, each follows a similar trajectory to 2050 with the lowest emissions under scenarios 2 and 4 where there are lower waste arisings and lower waste composition as outlined within the modelling assumptions.

Figure 2: Comparison of GHG emissions by scenario



All four scenarios achieve a reduction in scope 1 emissions of between 78% to 83% from 2022 to 2050. Out of the four modelled scenarios, the lowest emissions in 2050 are approximately 2.7 MtCO2e, under scenario 4 where the modelling assumptions include low arisings and low waste composition. Emissions are lower as there is less organic waste being treated at AD/composting facilities and consequently less emissions being generated.

In all four scenarios, this transition to lowered emissions is predominantly driven by the diversion of waste away from landfill and EfW, with EfW facilities further transitioning to incorporate CCS.

Infrastructure and Costs

The tonnage of waste being sent to landfill is estimated to decline year on year across all scenarios from the baseline of an approximate 43Mt. In 2050 the highest tonnage estimated to be sent to landfill is 10Mt from scenario 1.

The results of the NZP modelling show the use of MRF increasing significantly over the time period. As a result of the diversion of materials away from the lower tiers of the waste hierarchy, namely landfill and EfW, larger quantities of materials will need to be recycled, resulting in a need for increased MRF capacity.

In 2035, the estimated additional capacity requirements for MRF under the lowest scenario are 22Mt and an estimated 29Mt under the highest scenario. In 2050, this further equates to an additional capacity of 57Mt under the lowest scenario and 76Mt under the highest scenario.

When looking at the core DMR MRF materials (glass, metallic wastes, paper and cardboard, and plastics) the total capacity requirements range from 21Mt under the lowest scenario and 24Mt in the highest. In 2050 the totals for these materials are an approximate 23Mt under the lowest scenario and 32Mt under the highest.

The modelled infrastructure costs highlight that the largest investment will need to be in MRF technologies, which aligns with the increase in the use of this type of facility. Bulking facilities are typically cheap as they do not require any complicated process technology, and as such the cost associated with those is relatively static.

The capex investment for new MRFs will vary widely and based upon factors such as the technology type, automation, tonnage/throughput, and specific material streams. A high-level capex cost estimate for the low and high-capacity requirements in 2035 would be estimated to be in the range of £7 to £9 billion.
In 2050, this estimated capex cost would be in the range of £17 to £23 billion. This is assuming a year-on-year inflationary rise of around 2%. It should be noted that these cost ranges are at the upper end of estimations for this technology type.

The baseline composting capacity of 5Mt is estimated to increase within scenarios 1 and 3. The largest capacity demand exists under scenario 3 which equates to an estimated 7Mt in the year 2050. A high-level capex cost estimate for the additional 2Mt of capacity would be approximately £50 million pounds.

AD capacity requirements vary over the scenarios. The baseline AD capacity requirement modelled is approximately 3Mt. In 2035, the estimated additional capacity requirements under the lowest scenario are 1Mt and an estimated 2Mt under the highest scenario. In 2050 the lowest additional capacity requirements are estimated to be approximately 1Mt while the highest additional capacity requirements would be 3Mt under the scenario where there are higher arisings and higher quantities of organic wastes.

A high-level current capex cost estimate for the low and high-capacity requirements in 2035 would be estimated to be in the range £190 to £380 million pounds. In 2050, this estimated capex cost would be in the range of £190 to £570 million pounds. It is impossible to predict how many facilities may be required as AD facility capacities vary widely. Facilities may range from farm scale sites processing a few thousand tonnes per year through to industrial scale facilities processing 100kt per year. The scale of facilities will be based on several factors including availability of feedstocks in any given area, the energy content of the feedstocks processed, availability of offtake markets and more.

EfW capacity is modelled to reduce from the baseline capacity of approximately 17Mt under all modelled scenarios, with a transition from EfW to EfW with CCS starting in 2030.

The estimated capacity requirements for EfW in 2042 (including both EfW and EfW with CCS) in the lowest scenario are approximately 12Mt (scenario 4). The highest capacity requirements are approximately 16Mt (scenario 3). In 2050 the lowest capacity requirements are estimated to be an approximate 9Mt and highest requirements approximately 14Mt under the same scenarios.

A high-level current cost estimate for the low and high-capacity requirements of EfW in 2035 would be estimated to be in the range of £2 to £3 billion, and for EfW with CCS in the range of £700 to £1000 million. In 2050, this estimated cost would be in the range of £200 to £920 million for EfW, and for EfW with CCS in the range of £2.5 to £4 billion.

Enhanced Circularity Pathways

Modelled Scenarios

To develop the ECPs, twelve different future recycling rate scenarios have been developed. Three for each of the two main scenarios focusing on future potential waste arisings, and the two scenarios factoring in differences in waste composition. The twelve scenarios modelled are:

Table 1: List of Enhanced Circularity Pathway Scenarios

Scenario	Recycling	Name
Scenario 1: High Arisings	High	S1H
	Medium	S1M
	Low	S1L
Scenario 2: Low Arisings	High	S2H
	Medium	S2M
	Low	S2L
Scenario 3: High Arisings + High Composition	High	S3H
	Medium	S3M
	Low	S3L
Scenario 4: Low Arisings + Low Composition	High	S4H
	Medium	S4M
	Low	S4L

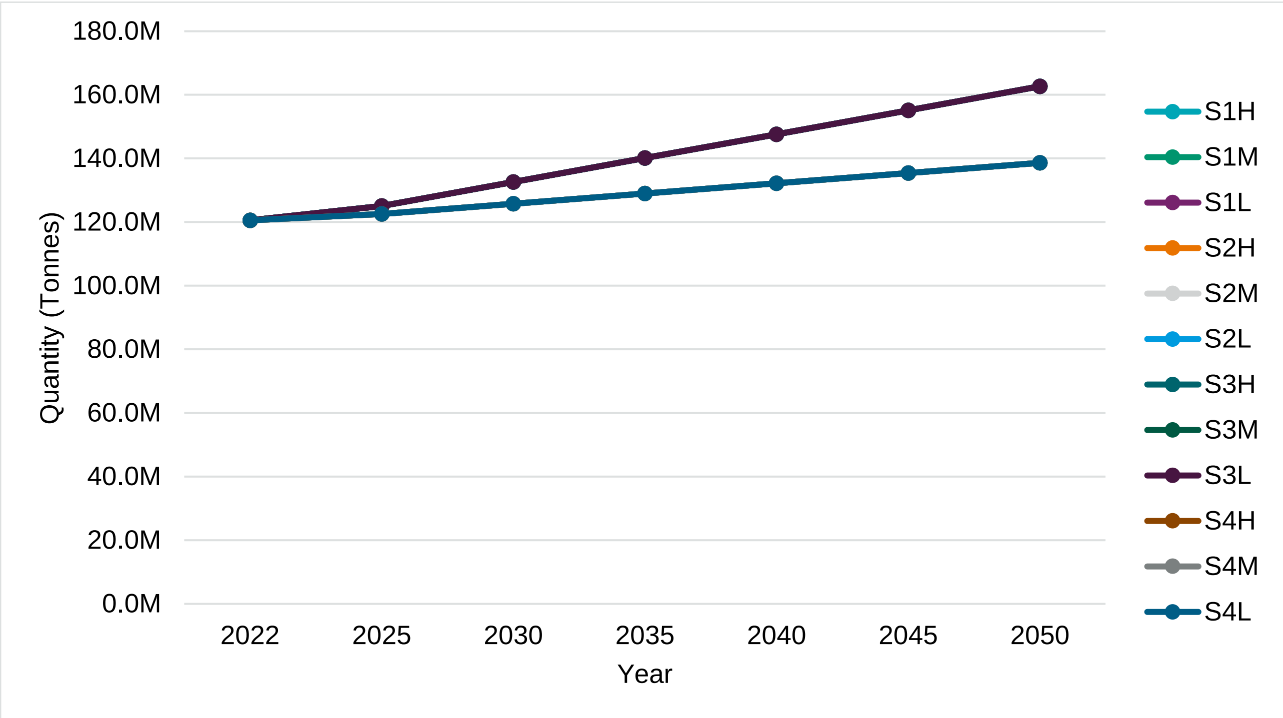
For each of the scenarios identified above, the ECP model calculated how the following variables change from the baseline year (2022) to 2055:

1. Environmental impact categories (global warming potential, acidification, eutrophication, freshwater aquatic toxicity, human toxicity, and depletion of abiotic resources).
2. Costs
3. Recycling rate

Enhanced Circularity Pathway Results

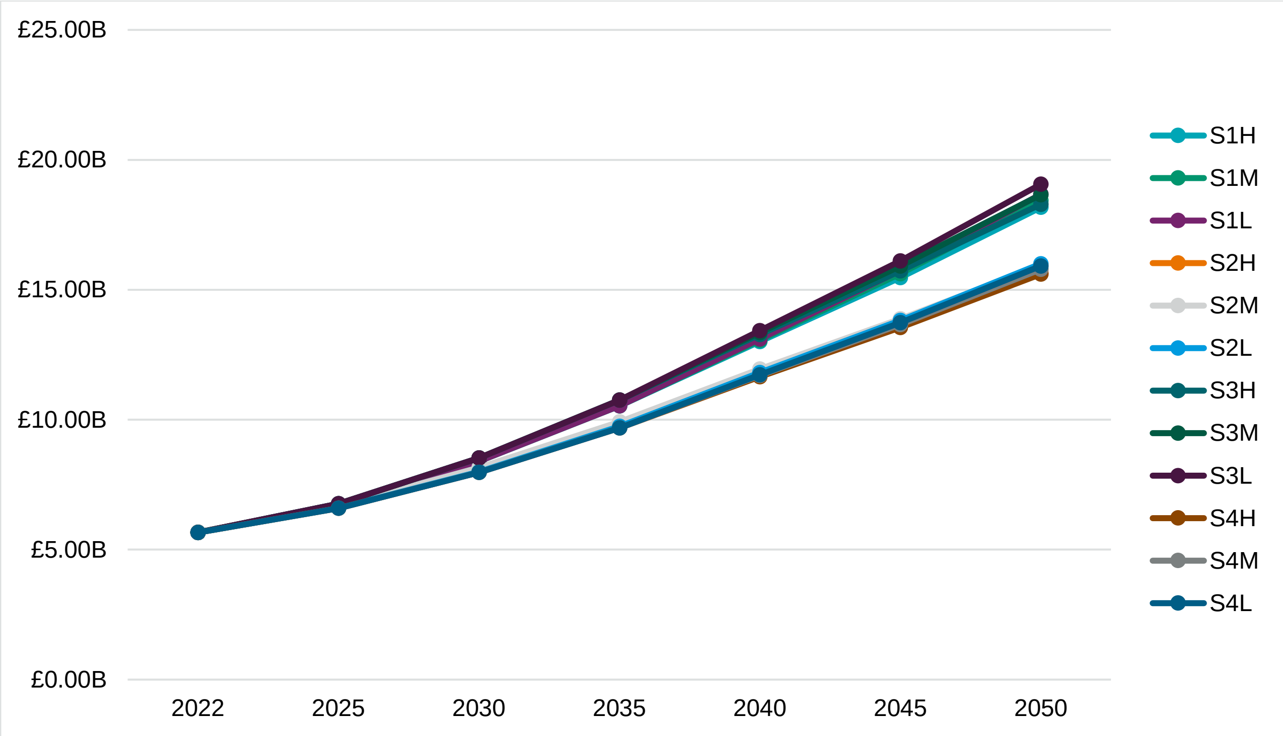
In 2050 it is expected that the total tonnage of waste in England will rise in every scenario compared to the baseline year in 2022, shown in Figure 3. Therefore, even under the low scenario assumptions, in 2050 at the end of the projected period, an approximate additional 20Mt of waste will need managing in England.

Figure 3: Comparison of total tonnes by scenario



The projected tonnage is identical for scenarios 1 and 3 and for scenarios 2 and 4, across all recycling rate options. This is because scenarios 1 and 3 both have high waste arisings assumptions, with scenarios 2 and 4 following low waste arisings assumptions.

Figure 4: Comparison of cost (Capex + Opex) by scenario



Infrastructure and Costs

The tonnage of waste being sent to landfill is estimated to decline year on year across all scenarios and recycling rate options from the baseline of an approximate 43Mt. In 2050 the highest tonnage estimated to be sent to landfill is 10Mt from scenario 1 (low, medium, high).

The results of the ECP modelling show the use of MRF increasing significantly over the period. As a result of the diversion of materials away from the lower tiers of the waste hierarchy, namely landfill and EfW, larger quantities of materials will need to be recycled, resulting in a need for increased MRF capacity.

In 2050, the estimated total capacity requirements for MRF under the lowest scenario and recycling rate option is 108Mt in S2L, and an estimated 130Mt under S1H, the highest scenario and recycling rate option.

The modelled infrastructure costs highlight that the largest investment will need to be in MRF technologies to meet the enhanced circularity targets, this aligns with the increase in the use of this type of facility. Bulking facilities are typically cheap as they do not require any complicated process technology, and as such the cost associated with those is relatively static.

The capex investment for new MRFs will vary widely and based upon factors such as the technology type, automation, tonnage/throughput, and specific material streams. A high-level capex cost estimate by 2050 would be in the range of £11 to £23 billion pounds.

The baseline composting capacity of 5Mt is estimated to increase across all scenarios and recycling rate options. The largest capacity demand exists under scenario 3 (low, medium, high) which equates to an estimated 6.5Mt in the year 2050. A high-level capex cost estimate for the additional capacity would result in approximately £50 million pounds.

AD capacity requirements vary over the scenarios and recycling rate options. The baseline AD capacity requirement modelled is approximately 3Mt. In 2050 the lowest total capacity requirements are estimated to be approximately 4.2Mt in S4L. The highest total capacity requirements would be 8Mt under the scenario where there are higher arisings, higher quantities of organic wastes, and higher circularity rates in S3H.

A high-level current capex cost estimate for 2050 would be in the range of £190 to £570 million pounds.

EfW capacity is modelled to reduce from the baseline capacity of approximately 17Mt under all modelled scenarios and recycling rate options. There is a transition to EfW with CCS with this capacity modelled to become available in 2030.

In 2050 the lowest capacity requirements are estimated to be an approximate 7.7Mt under the high recycling rate option for scenario 4, with the highest requirements approximately 12.8Mt under low recycling rate option for scenario 3.

Environmental impact categories

The impact on global warming potential reduces from a 2022 baseline of 16Mt CO2e, by approximately 13Mt CO2e across all scenarios, down to between 2.5 to 3.1Mt CO2e in 2050. This is a result of diverting waste up the waste management hierarchy, from landfill and EfW to recycling.

The results show that Scenarios 2 and 4 have the lowest global warming potential impacts, with the high recycling options resulting in the lowest emissions among the three options. This highlights the main factor impacting emissions is the amount of tonnage treated in the scenarios, with more waste being diverted resulting in fewer emissions during the processing of the waste.

This analysis on global warming potential is not taking the offset of virgin production into consideration, having only considered scope 1 and 2 emissions in line with net zero legislation. Therefore, this result shows the difference in emissions generated by the processing of waste. If the offset virgin materials were to be included the results of this analysis could change, as the high arisings scenarios 1 and 3 which are generating more waste would then generate more materials which can be used to substitute virgin materials, with increases in recycling offering an opportunity to reduce carbon emissions.

The five other impact categories of acidification, eutrophication, human toxicology, freshwater aquatic ecotoxicology, and depletion of abiotic resources do consider the impacts from Scope 1, 2 and 3 emissions within this analysis. Therefore, they are offsetting the production of virgin materials resulting in reduced emissions. For acidification, freshwater aquatic ecotoxicology, human toxicology, and depletion of abiotic resources, the biggest potential savings are shown in scenario 3, whilst eutrophication shows the biggest saving in scenario 4. This bolsters the indication that the more materials being sent to recycling and thus offsetting virgin material generation, the bigger environmental saving can be obtained.

CONTENTS

1. INTRODUCTION

Every five years, the National Infrastructure Commission (the Commission) publishes a National Infrastructure Assessment. Each Assessment analyses the UK's long term economic infrastructure needs, outlining a strategic vision over the next thirty years and setting out recommendations for how identified needs should be met.

The Commission is now working on the second National Infrastructure Assessment, to be published in autumn 2023. This Assessment will make recommendations to government that support delivery of a thirty-year plan for the UK's economic infrastructure covering energy, transport, digital, waste, water and wastewater, and flood resilience.

The Commission wished to appoint a specialist supplier to provide waste sector research and modelling capabilities to support it to develop its waste sector recommendations in the assessment.

The research and modelling were to focus on the challenge the Commission highlighted as a priority for the waste sector in its Baseline Report[1], to "examine the role of the waste sector in enabling the move towards a more circular economy". The next National Infrastructure Assessment will include recommendations to government on the role of the waste sector in reaching net zero targets and moving towards a more circular economy.

1.1 SCOPE

Ricardo Energy & Environment (Ricardo) were commissioned to provide this specialist waste sector research and modelling to support the Commission's recommendations to the UK Government. The scope of work involved the delivery of three workstreams:

- **Workstream 1 – Net Zero Pathways:** Assess the current performance of the waste sector in terms of capacity, cost, and environmental impact (carbon). Develop and model the least cost infrastructure pathway for the waste sector to meet the sixth carbon budget by 2035 and net zero by 2050 across different arisings scenarios. This should include quantification of required infrastructure capacity, its costs and benefits. The scope of this workstream is all waste streams and sources except hazardous and nuclear waste.
- **Workstream 2 – Enhanced Circularity Pathways:** Gather evidence to identify waste streams with the greatest a) negative environmental impact of extraction and processing and b) potential for circularity. Model the capacity and mix of infrastructure, otherwise known as enhanced circularity pathways, required to deliver different circularity targets for each waste stream. Part of this assessment will include developing a cost-effectiveness metric for each target related to greatest avoided environmental damage per pound spent. This will allow the Commission to determine the preferred circularity target for each identified waste stream. The circularity target for each waste stream will be fed back into each net zero pathway from workstream 1 to determine an overall level of circularity.
- **Workstream 3 – Assessment of Policy Effectiveness:** An assessment of the strengths and weaknesses of current and proposed policy instruments in improving the circularity of the waste system.

This report outlines our methodology and results for Workstream 1 – Net Zero Pathways and Workstream 2 – Enhanced Circularity Pathways.

1.1.1 Workstream 1: Net Zero Pathways

The scope of this workstream involved reporting current waste tonnages, broken down by the volume (measured in tonnes) of current waste sources and streams, alongside the current capacity and cost of waste infrastructure required to process the current waste tonnages. This was disaggregated by waste infrastructure technology (proportion of waste recycled, incinerated, landfilled, and treated by other methods) and the tonnage of waste from each source and stream for each waste infrastructure technology.

[1] Revised-Second-National-Infrastructure-Assessment-Baseline-Report.pdf (nic.org.uk)

Current waste sector performance was used as a baseline comparison for the future net zero pathways and an assessment of the waste sector's current environmental impact and level of circularity for the waste sector as a whole and by waste stream.

1.1.2 Scenarios of future waste arisings and composition

Four scenarios have been developed for the possible future path of waste arisings. These are reported both as total waste arisings and disaggregated by waste source (i.e., local authority, commercial and industrial, construction and demolition) and waste stream.

These scenarios also consider changes in the composition of materials in each source/stream to investigate the type of infrastructure required to effectively manage the waste quantities.

1.1.3 Modelling least cost net zero pathways

The objective of workstream 1 was to determine the net zero pathway for the waste sector according to different waste arising scenarios.

To meet GHG reduction targets, net zero pathways either divert waste streams to less GHG emitting waste infrastructure technologies or apply emission abatement technologies to what are currently more GHG emitting waste infrastructure technologies.

A pathway describes the mix and capacity of different waste infrastructure and emissions abatement technology, defined by the different proportions of each waste stream that end up recycled, incinerated, landfilled, and processed by other waste infrastructure technologies. All pathways were developed from the same menu of infrastructure technologies and are compatible with GHG reduction targets and government commitments.

The net zero pathways were presented as profiles over time reflecting assumed timings to deliver the required technology mix and capacity. For each scenario and pathway, the mix and capacity of waste infrastructure and associated emission abatement technology required, incremental costs (relative to today, not a future counterfactual) and total systems costs are reported for all waste streams excluding hazardous and nuclear.

1.1.4 Workstream 2: Enhanced Circularity Pathways

The scope of this workstream involved reducing raw material use through improved circularity of the net zero pathways determined in workstream 1. For each net zero pathway determined in workstream 1, workstream 2 models the capacity and mix, otherwise known as enhanced circularity pathways, required to deliver three different circularity levels for each priority waste stream (or material) identified as having the greatest potential for reduction in environmental impact through increased circularity.

Current waste sector performance was used as a baseline comparison for the future net zero pathways and an assessment of the waste sector's current environmental impact and level of circularity for the waste sector as a whole and by waste stream.

1.1.5 Identify priority waste streams for circularity

Priority waste streams for circularity were identified in workstream 1. All waste streams were assessed (excluding biowaste, hazardous and nuclear waste), to identify the candidate waste streams (or significant materials within a stream) for circularity. This assessment was presented to NIC to decide the priority waste streams based on the total environmental impact (scale) avoided by bringing materials back into productive use and the technical potential for increasing circularity through infrastructure.

1.1.6 Development of enhanced circularity pathways

For each net zero pathway and priority waste stream (or material) identified, an enhanced circularity pathway was developed representing a spectrum of recycling rates which achieve different circularity levels. The enhanced circularity pathways are defined by the mix and capacity of waste infrastructure technology associated for each waste stream and circularity target.

1.1.7 Modelling enhanced circularity pathways

The level of circularity achieved for each least-cost net zero pathway in workstream 1 acts as a baseline level which the enhanced circularity pathways aim to increase. For each enhanced circularity pathway, we have modelled the capacity, cost and environmental impact of different circularity targets achieved through enhanced circularity pathways for each priority waste stream (or material).

2. MODELLING METHODOLOGY

2.1 BASELINE WASTE TONNAGE

Data was obtained from the Environment Agency's Waste Data Interrogator[2] for the most recent year of available data, 2021. The total waste quantities were split into three waste streams of commercial & industrial (C&I), construction & demolition (C&D) and local authority collected waste (LACW). Analysis was undertaken on the fate of the different waste streams and the type of waste management facility handling the material. The waste streams were further disaggregated into 32 material categories, outlined below:

1. Acid, alkaline or saline wastes.
2. Animal and mixed food waste.
3. Animal faeces, urine and manure.
4. Batteries and accumulators wastes.
5. Chemical wastes.
6. Combustion wastes.
7. Common sludges.
8. Discarded equipment (excluding discarded vehicles, batteries and accumulators waste).
9. Discarded vehicles.
10. Dredging spoils.
11. Glass wastes.
12. Health care and biological wastes.
13. Industrial effluent sludges.
14. Metallic wastes, ferrous.
15. Metallic wastes, mixed ferrous and non-ferrous.
16. Metallic wastes, non-ferrous.
17. Mineral waste from construction and demolition.
18. Mineral wastes from waste treatment and stabilised wastes.
19. Mixed and undifferentiated materials.
20. Other mineral wastes.
21. Paper and cardboard wastes.
22. Plastic wastes.
23. Rubber wastes.
24. Sludges and liquid wastes from waste treatment.
25. Soils.
26. Sorting residues.
27. Spent solvents.
28. Textile wastes.
29. Used oils.
30. Vegetal wastes.
31. Waste containing PCB.
32. Wood wastes.

[2] https://www.data.gov.uk/dataset/d8a12b93-03ef-4fbf-9a43-1ca7a054479c/2021-waste-data-interrogator

When comparing these statistics with the Defra UK statistics on waste, the total tonnages within this analysis are lower than the Defra figure due to the facility types included in the analysis. (Not all facility types within the WDI have been included). The difference in total tonnage is accounted by the extra tonnes captured in facility types that are not included within the scope of this analysis (for example, biological treatment of wastewater, nuclear and hazardous waste treatment, and temporary storage installations).

The quantities of waste materials, per the disaggregated waste streams were then analysed for the quantities of material going to eight defined destinations (or facility types) for the baseline year as listed below:

1. Landfill.
2. Energy from Waste (EfW).
3. Mechanical Biological Treatment (MBT).
4. Material Recycling Facility (MRF)*.
5. Other Bulking^.
6. Composting.
7. Anaerobic Digestion (AD).
8. Advanced Thermal Treatment (ATT).

*For the purposes of this project, the 'Material Recycling Facility' facility type represents ALL mechanical recycling including aggregate recycling, metal reprocessing, wood recycling and many other processes. Due to the reporting method in the WDI, this facility type also includes some organic waste recycling such as cooking oil recycling, composting pre-treatment and others. Additionally, this facility type represents both the initial stage of sorting recyclate as well as downstream processing to prepare materials for manufacturing.

^The 'Other Bulking' facility type represents waste going through transfer stations. Since these transfer stations are intermediate destinations, this waste would present itself again at processing, treatment and disposal destinations. For this reason, to avoid double-counting, waste in the 'Other Bulking' category was excluded. Additionally, within the LACW stream, the waste category 'household and similar wastes' was disaggregated with the tonnages going into the other waste streams. This disaggregation process is detailed in Section 2.1.1.

2.1.1 Disaggregation of 'household and similar wastes'

Of the 53M tonnes of local authority collected waste in the baseline year, almost 37M tonnes is classified as 'household and similar waste'. Since this material category can represent a mix of various materials, it was disaggregated by multiplying the waste quantity by the most up-to-date publicly available waste composition data for household and similar waste. The assumed waste composition sourced from WRAP's national study[3] is provided in Table 2. Once the 'household and similar wastes' waste was disaggregated, it was added to the remaining local authority collected waste.

Table 2: Composition Assumption for Household and Similar Wastes

Material	Proportion
Animal and mixed food waste	29.35%
Animal faeces, urine and manure	3.90%
Discarded equipment (excluding discarded vehicles, batteries and accumulators waste)	1.75%
Glass wastes	2.94%
Metallic wastes, ferrous	1.86%
Metallic wastes, non-ferrous	1.17%
Mineral waste from construction and demolition	6.52%
Mixed and undifferentiated materials	13.89%

[3] https://wrap.org.uk/sites/default/files/2021-10/WRAP-national-household-waste-comparison-2017.pdf

Material	Proportion
Paper and cardboard wastes	12.69%
Plastic wastes	13.06%
Textile wastes	7.59%
Vegetal wastes	3.84%
Wood wastes	1.44%
Total	**100.00%**

2.2 WASTE FORECASTING

Waste forecasting involves modelling how waste may change in the future. The forecasting component of this project examined changes in waste arisings and waste composition. There are significant cultural, social and economic factors that impact the quantity and composition of waste. For this reason, the approach has been to explore a range of feasible possibilities (by examining various scenarios) rather than depict what England's actual waste arisings and composition may look like in the future. It was decided that this component would explore scenarios that set the potential upper and lower bounds for forecasted waste arisings and the waste composition scenarios. To this end, four forecasting scenarios were determined:

1. Scenario 1: High Arisings
2. Scenario 2: Low Arisings
3. Scenario 3: High Arisings + High Composition
4. Scenario 4: Low Arisings + Low Composition

2.2.1 Waste Arisings Scenarios (Scenarios 1 and 2)

The scenarios for future potential waste arisings consist of a high scenario and a low scenario. In both scenarios, the established baseline waste tonnages for C&I, C&D and LACW are projected from their 2022 baseline year through to 2055. Forecasting examines the total waste arisings in each of the three waste sources (C&I, C&D, LACW) rather than quantities of individual materials (such as wood or paper). Total waste arisings from each source are more stable than trends in specific waste materials. This is because the total of materials within the source will account for variances between the materials that might appear more extreme on a smaller scale and make for a more reliable trend to forecast by.

Waste arisings are affected primarily by economic factors (such as population, and income levels) and policy factors (such as environmental legislation)[4]. Looking at historical waste arisings, it is difficult to decouple changes that have occurred due to economic factors from those that have occurred due to policy measures. The forecasting method detailed below focuses on predicted economic indicators. Predicted economic indicators tend to be less volatile than the predicted impacts of policy measures as policies may be changed or may not be as impactful as the policy targets imply. By forecasting arisings based only on predicted economic indicators, it provides an indication of base level quantities onto which future policy measures can be applied if required. Impacts to waste arisings because of future policy measures have not been applied to evaluate these separately.

2.2.1.1 Forecasting Method

The method used to forecast future waste arisings is detailed below.

1. Published historical waste arisings data was collated[5].
2. The Commission conducted a literature review exercise looking at waste arising projections in 2022. The data from these reports was analysed. The reports are:

[4] https://www.researchgate.net/publication/222430349_Growth_in_global_materials_use_GDP_and_population_during_the_20th_century

[5] Data available 2010- present. https://www.gov.uk/government/statistical-data-sets/env23-uk-waste-data-and-management

   a. National Infrastructure Assessment: Waste Infrastructure Analysis for England (2018)[6]
   b. Energy from waste: A new perspective (2021)[7]
   c. UK residual waste: 2030 market review (2017)[8]
3. Relevant indices (i.e., those that could have a causal link with waste arisings) were examined. For this forecasting we examined the following:
   a. Gross Domestic Product (GDP)[9]
   b. England household numbers[10]
   c. Population figures for England[11]
   d. England construction output[12].
4. Regression analysis was conducted to understand and calculate the relationship between GDP and historical waste arisings. Regression analysis was also conducted between population and historical waste arisings as this relationship is commonly used in the waste industry to predict waste arisings and further informs the industry expert judgement applied in step 6.
5. Waste arisings were projected to 2055 using the results from the regression analysis, and GDP projections in line with the NIC's growth scenarios.
6. Expert judgement was used to compare the projected waste arisings to projections collected from reputable reports (step 2), then estimate an upper and lower limit for total waste arisings.

2.2.1.2 Forecasting with Historical Data

To understand how waste arisings will change in the future, it is important to understand the relationship between relevant indices and waste generation.

A literature review was carried out to understand the relationship between waste arisings and GDP. The literature identified that in general, increased economic growth on a per capita basis increases solid waste generation. This is due to an increase in consumption as a result of higher personal disposable income at an individual level, and higher production and research and development (R&D) at a national level[13,14]. Expert opinion within Ricardo, as well as evidence from literature[15] determined that there is also a strong correlation between waste arisings and population simply due to more people requiring more resources. Ricardo experts also expressed that the industry norm is to project waste generation against population estimations.

2.2.1.3 Regression Analysis

Using historical data collection on waste arisings, GDP and population, linear regression analysis was conducted to identify relationships. Actual data found for 2020 and 2021 was excluded in the analysis to avoid the effects of the COVID-19 pandemic which caused a variance in waste arisings. As an example, the COVID-19 pandemic impact resulted in increases in residual waste from households, with a reduction in C&I wastes[16].

The analysis involved an econometric regression of the Dependent Variable (i.e., the waste arisings) on each of the independent variables (GDP and population), which examined the first difference of all variables, and controlled for the first lag of the dependent variable. By completing the regression of differences, omitted variables in the form of fixed effects are differenced out and therefore not included in the error term. Moreover, by including the one-period lagged dependent variable, omitted variables are captured by this lag, which is taken as proxy but subject to approximation error. This is an autoregressive time-varying approach to control for omitted variable bias, which was most suitable considering the data available. This approach is

[6] https://nic.org.uk/app/uploads/NIC-Anthesis-Report-and-Appendicies-FINAL-1.pdf
[7] https://www.rolandberger.com/en/Insights/Publications/Energy-from-Waste-A-New-Perspective-2.html
[8] https://www.tolvik.com/wp-content/uploads/2017/11/UK_Residual_Waste_Capacity_Gap_Analysis.pdf
[9] https://www.ons.gov.uk/economy/grossdomesticproductgdp/timeseries/abmi/pn2
[10] https://www.ons.gov.uk/peoplepopulationandcommunity/populationandmigration/populationprojections/datasets/householdprojectionsforengland
[11] https://data.worldbank.org/indicator/SP.POP.TOTL
[12] https://www.gov.uk/government/statistical-data-sets/env23-uk-waste-data-and-management
[13] https://pmemaster.env.duth.gr/wp-content/uploads/2019/06/Namlis-and-Komilis-2019.pdf
[14] https://www.sciencedirect.com/science/article/abs/pii/S0956053X20303494
[15] https://www.oecd-ilibrary.org/sites/2bf17284-en/index.html?itemId=/content/component/2bf17284-en
[16] https://www.tolvik.com/published-reports/view/briefing-covid-19-and-uk-waste-sector-autumn-2020/

recommended as the standard approach to address omitted variable bias[17]. Adding more controls would have reduced the power, which is not recommended when the time series is short. The dependent variable lag approach is a catch-all, independent of the form of the omitted variable.

The stationarity of all the variables used has also been tested, to rule out spurious correlations. A Dicky-Fuller unit root test was performed for all data series. These tests were conducted using the current specification that takes the first difference for all regressors, both with and without trend. The results rejected the hypothesis of non-stationarity. For completeness, non-linear forms were also tested and yielded weaker relationship results.

The analysis found that there is an associational quantitative link between GDP and total waste arisings and that, out of the indices that were tested, GDP is the best single predictor of waste arisings. Since GDP reflects population growth as well as improvements in per capita consumption, it is not surprising that this measure shows the strongest relationship with waste arisings.

Table 3: Summary of regression results between waste arisings and indices

Waste Type	Indicator	R Square	p value
Household and C&I	GDP	0.61	0.008
C&D	GDP	0.84	0.0002
Total	GDP	0.86	0.0001
Household and C&I	Population	0.59	0.01
C&D	Population	0.78	0.0007
Total	Population	0.80	0.0004

An r-squared value of 1.00 means 100% of the variance in waste arisings can be explained by the indicator. A p value <0.05 indicates statistically significant result.

2.2.1.4 Regression Analysis Results

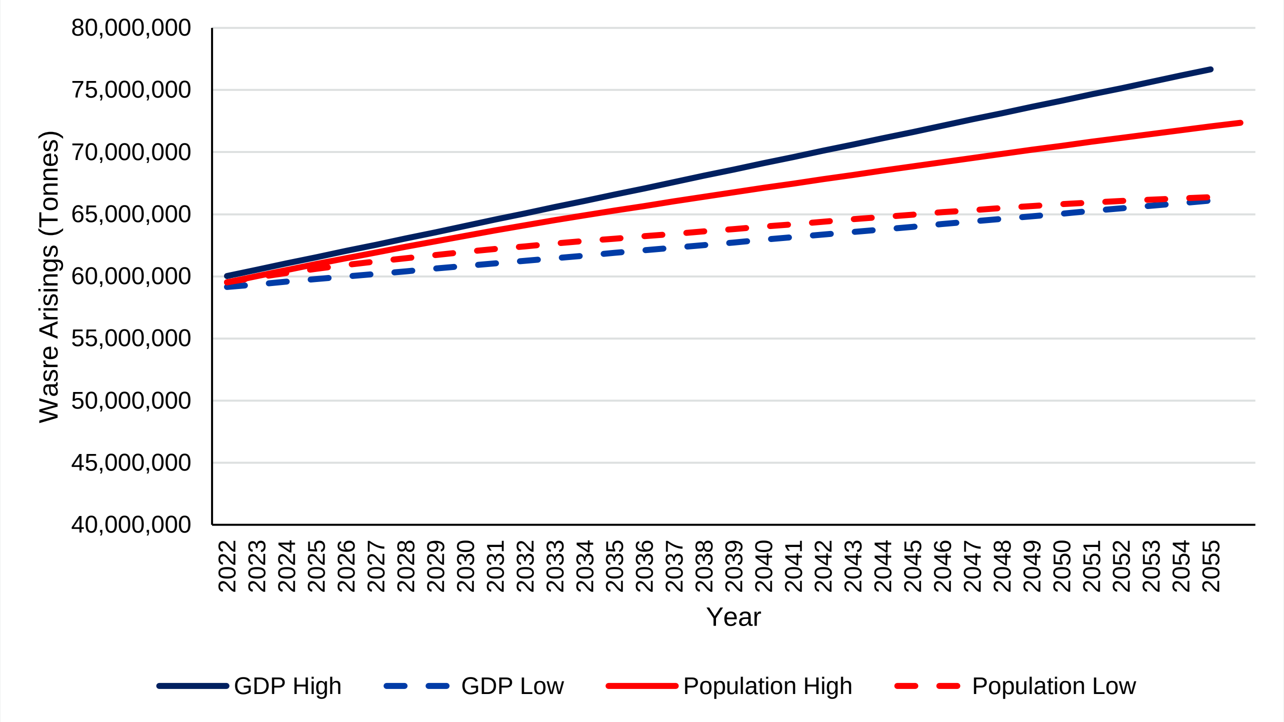
Using the regression analysis and collected projections of indicators from reputable sources, a range of forecasts were developed based on:

1. High GDP scenario
2. Low GDP scenario
3. High population scenario
4. Low population scenario

The results of this analysis are shown in Figure 5.

[17] Wooldridge, J.M. (2002) Introductory econometrics a modern approach. Australia: South-Western College Publishing.

Figure 5: Waste Arisings Forecasts - Regression



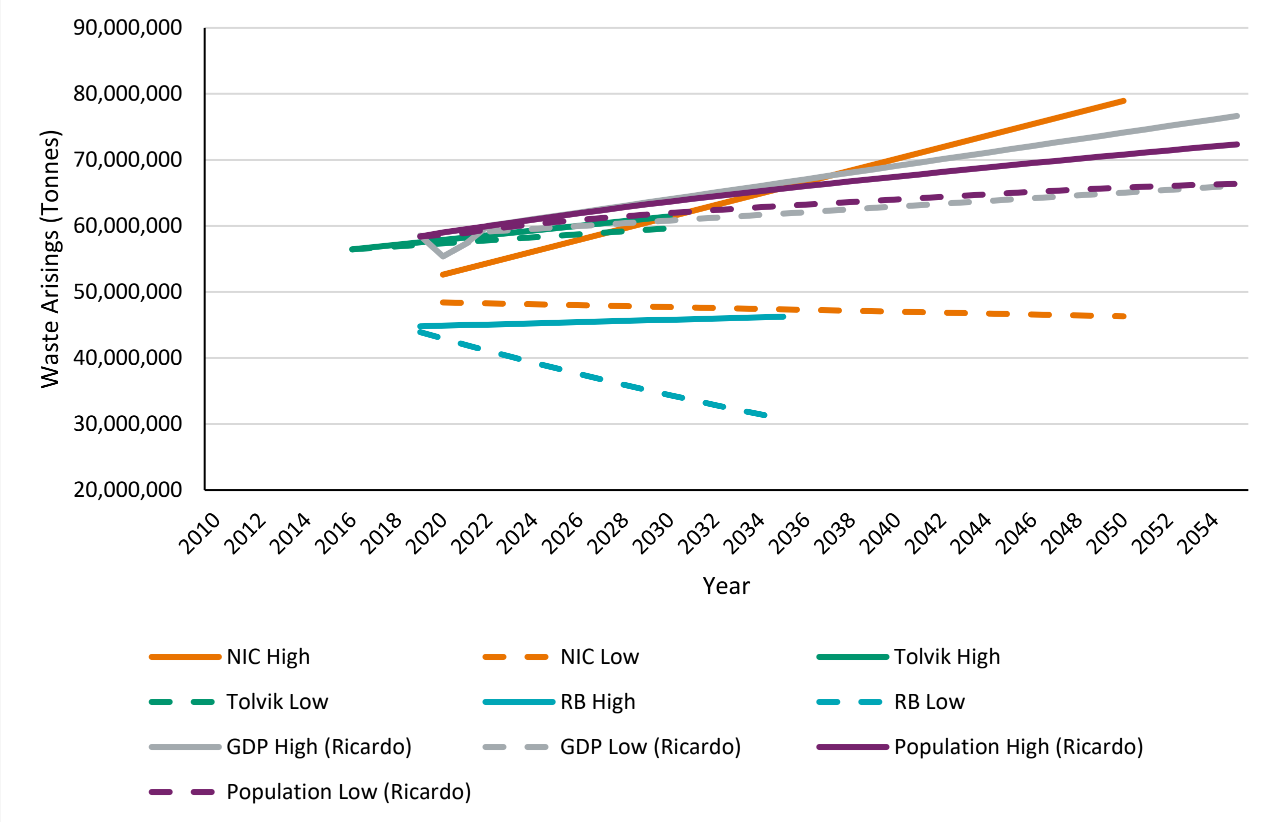
2.2.1.5 Comparison with Published Projections

Recent studies published by NIC (2018)[18], Roland Berger (2021)[19] and Tolvik (2017)[20] have modelled various scenarios to project future waste arisings. In all three cases, Ricardo looked at the closest scenario to 'business as usual' i.e., no change to policy or infrastructure, if possible. NIC's (2018) Report outlines a 'business as usual' baseline for Local Authority Collected Waste (LACW) and household-like C&I to 2050, with the same Energy from Waste (EfW) infrastructure conditions that were expected in 2020. Projections were made based on population and economic growth forecasts. The report by Roland Berger projected waste arisings to 2035 but focused on EfW-addressable waste, i.e., a subset of residual waste only. It used population growth to predict household waste arisings and economic growth to predict C&I waste arisings. Its high waste scenario is based on incremental change with no government intervention and its low waste scenario outlines radical change with significant government intervention. Tolvik's study is an amalgamation of a number of studies done by waste companies such as Suez and Biffa. The high waste scenario modelled 'business as usual' and the low waste scenario was based on high recycling rates, which does not apply to total generation, but it assumed other policies were in place to lower overall waste. Population projections were used to make these projections.

The projections outlined above were collated and normalised to make them comparable. As the projections examined residual waste only, the relevant recycling rates reported were used to normalise the data to estimate the total waste generation. These collated and normalised findings are shown in Figure 6. Note that all projections exclude C&D waste.

[18] Waste infrastructure analysis for England - NIC
[19] Energy from Waste: A New Perspective | Roland Berger
[20] UK Residual Waste: 2030 Market Review - Tolvik

Figure 6: Comparison of calculated and reported forecasts (household and C&I waste arisings)



2.2.1.6 *Arisings Scenario Results*

The forecasts for household and C&I waste based on GDP and population regression findings were plotted alongside the forecasts found in the literature. A range of waste data experts within Ricardo examined the evidence and provided estimates based on their experience and agreed on the limits as follows:

1. Upper limit in 2055 for LACW and C&I waste arisings: 80 million tonnes
2. Lower limit in 2055 for LACW and C&I waste arisings: 55 million tonnes

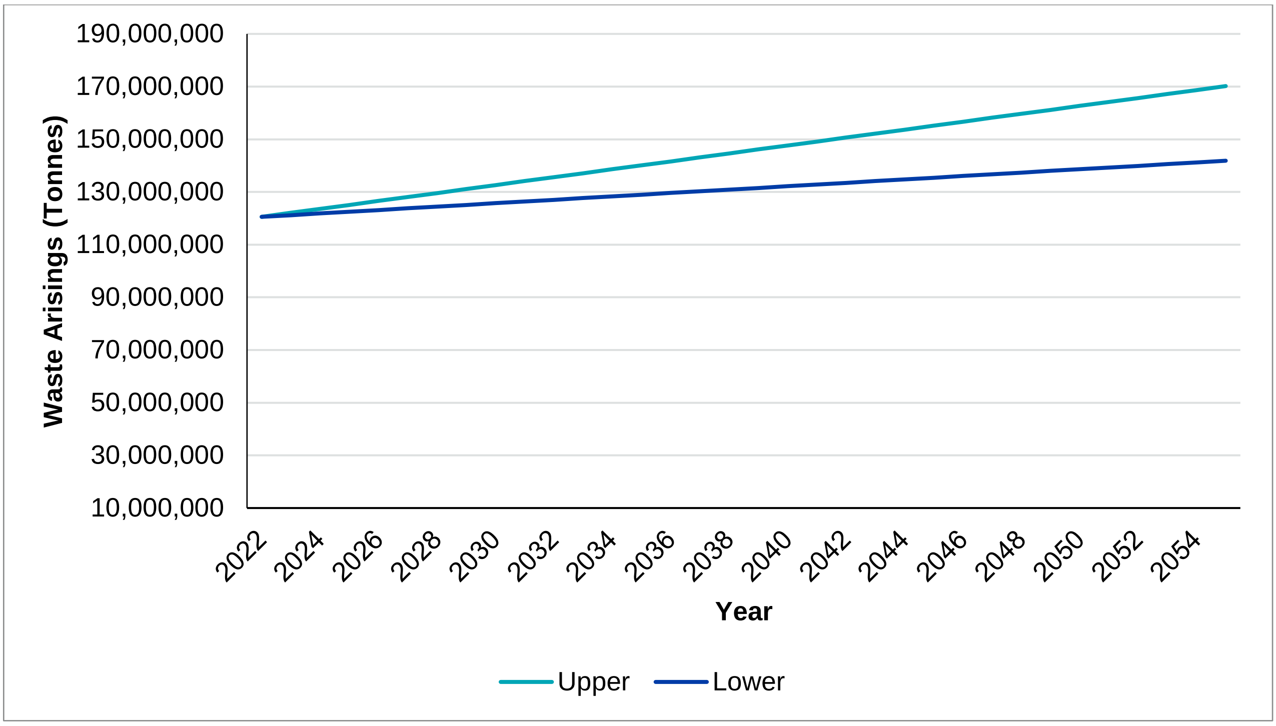
The limits were decided based on expert knowledge of the UK waste industry in the last 20 years, trends towards the circular economy[21,22,23], as well as changes to waste markets. Both the upper and lower limits also consider the impacts of existing policies and targets. The upper limit reflects the trajectories of the projections made by NIC and Ricardo's regression forecasts based on GDP and population, but also considers the growing momentum of the circular economy. The lower limit assumes that without any change to policy or attitude, waste generation (on a per-capita basis) is unlikely to reduce from to a level lower than 2022 levels. For this reason, the lower scenario shows a gradual increase, in line with population growth. The forecast estimates above only consider LACW and C&I waste and exclude C&D waste. The regression analysis indicated that GDP is an appropriate single predictor of C&D waste arisings, so the percentage increase and decrease determined from the forecast estimations were applied to total waste to include C&D waste. The proportion of waste arisings from each stream were adjusted to mirror those found in the baseline assessment. The final proposed upper and lower limits are:

1. Upper limit in 2055 for total waste arisings: 170 million tonnes
2. Lower limit in 2055 for total waste arisings: 142 million tonnes

The results are shown in Figure 7.

[21] Circular Economy Package policy statement - GOV.UK (www.gov.uk)
[22] Circular economy centres to drive UK to a sustainable future – UKRI
[23] Circular Economy Series | M&A | Trends | Investment | UK - BDO

Figure 7: Total waste arisings forecast



2.2.1.7 Method Benefits

Instead of assuming there is a relationship between GDP and waste arisings without providing evidence, the relationship has been established through a combination of regression analysis and a literature study. GDP is forecast by government departments and therefore deemed to be reliable. The combination of historical analysis, a review of recent forecasts and expert judgement to inform the forecasting is more robust than just one of these methods alone.

2.2.1.8 Method Risks

The long-term forecasting period for this project does lead to greater uncertainty, as the relationship between GDP and the quantity of waste generated is assumed to continue. This cannot account for system shocks or unexpected 'black swan' events (e.g., recession or war). The regression analysis excluded real data from 2020 as the COVID-19 pandemic significantly lowered both waste arisings and GDP away from the norm. This was done under the assumption that GDP and waste generation will recover to reflect pre-pandemic levels, and recent trends do affirm this assumption however this cannot yet be confirmed. This method is limited by the forecasts that are publicly available. The upper and lower limits were chosen based on an array of projections of household and C&I waste, as the literature excluded waste arisings from C&D. The upper and lower percentage bounds were applied to total waste, which includes C&D waste as there are no published comparable projections of C&D waste.

2.2.2 Waste Composition Scenarios (Scenarios 3 and 4)

Waste composition scenarios have been examined because the composition of waste impacts its associated carbon footprint. Inert materials such as glass and stone will emit no carbon during their lifespans, but only during their initial fabrication, forming, processing stages or during transportation. Biogenic waste made up of organic materials such as wood and plant waste will emit carbon dioxide (CO_2) as it naturally decomposes, and during processing, treatment, and disposal[24] along with methane (CH_4) as a product of decomposition under the anaerobic conditions found in landfill. However, this tends to be offset by the carbon absorbed during the growing phase. Biogenic waste can also emit methane (CH_4) when it decomposes anaerobically. This can occur during processing and treatment, but primarily occurs after disposal at landfills. Due to methane's significant warming potential, methane emissions from landfill are a large source of CO2e. Fossil-derived waste

[24] https://ghgprotocol.org/sites/default/files/standards_supporting/Ch5_GHGP_Tech.pdf

streams such as plastics are another source of carbon emissions as they will emit CO_2 and CH_4 during processing, treatment and disposal if burned during incineration, which are not offset in any way.

Waste composition is difficult to predict because it is impacted by several factors, such as:

1. Purchasing habits
2. Legislation/policy
3. Unexpected events

For example, the COVID-19 pandemic would be considered an unexpected event. It caused clinical waste to more than double as a result of increased hospitalisation and cardboard waste also increased from protective equipment packaging and the surge in online shopping during lockdowns[25].

Material composition trends are volatile and do not exhibit a strong relationship with economic indicators in the same way that total waste arisings do. This makes forecasting changes in waste composition a difficult task. Alternative methods for scenario development include reviewing literature, examining historical trends, examining established waste-related targets, or examining compositions of waste in similar countries. The issues with the first three approaches are outlined below:

- Literature: there are no recent and robust literature sources available on composition forecasts.
- Historical trends: it is not possible to determine which historical trends will continue and for how long.
- Targets: the current composition-related targets do not have clear mechanisms in place for their achievement. Additionally, the achievement or non-achievement of targets is not determinable.

This leaves examination of waste compositions from other similar countries. This approach also presents risks because there are significant cultural, social, and economic factors unique to each country that impact the composition of waste. For this reason, the approach has been to explore a range of feasible possibilities rather than depict what England's actual waste composition may look like in the future.

2.2.2.1 Identification of key materials

Three material groups have been identified as key to greenhouse gas emissions: food, plastics and paper and card. Globally, food waste has the highest impact, generating 6%[26] of global GHG emissions compared to 3.4% by plastics over its entire lifecycle[27] and 1.3% by paper[28]. In the UK, 9.5 million tonnes of food waste are generated annually which is associated with over 25 Mt of GHG emissions[29]. A study by DEFRA[30] (2022) found that organic waste accounted for 39% of the emissions associated with residual waste and recycling, compared to 19% by paper and card and 11% by plastics.

2.2.2.2 Existing Waste Targets

While waste targets have not been considered due to the issues raised above, the following information is presented for information.

Food

The Courtauld Commitment 2030 aligning with the UN Sustainable Development Goal (SDG) 12.3, sets a target of a 50% reduction in food waste per capita by 2030 vs the UK 2007 baseline[31]. This target covers food waste from households, manufacturing, retail, hospitality, and food service industries.

The Waste and Resources Strategy for England target is for the elimination of all avoidable waste by 2050. In the case of food waste, WRAP National Household Waste Composition 2017[32], indicated that avoidable food waste makes up 60% of total household food waste. That is food waste that prior to disposal was at one point edible, opposed to unavoidable food waste consisting of waste from food or drink preparation that is not normally considered edible at any point prior to disposal (e.g. bones, egg shells, tea bags).

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[25] https://publishing.rcseng.ac.uk/doi/full/10.1308/rcsbull.2020.138
[26] https://ourworldindata.org/food-waste-emissions
[27] https://www.oecd.org/environment/plastics/increased-plastic-leakage-and-greenhouse-gas-emissions.htm#:~:text=Throughout%20their%20lifecycle%2C%20plastics%20have,of%20global%20greenhouse%20gas%20emissions
[28] https://www.ucl.ac.uk/news/2020/oct/paper-recycling-must-be-powered-renewables-save-climate
[29] https://wrap.org.uk/taking-action/food-drink/actions/action-on-food-waste
[30] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1123468/Statistics_on_carbon_emmisions_Waste_Households_England_v8_2018.pdf
[31] https://wrap.org.uk/taking-action/food-drink/initiatives/courtauld-commitment
[32] https://wrap.org.uk/sites/default/files/2021-10/WRAP-national-household-waste-comparison-2017.pdf

Plastics

The Environmental Improvement Plan[33] published in January 2023 sets an interim plastic waste reduction target of 45% per person by 2028, with all avoidable plastic waste eliminated by 2042.

The Environmental Protection (Plastic Plates etc. and Polystyrene Containers etc.) (England) Regulations 2023 introduces a ban on some single-use plastic items from October 2023. This includes bio-based, biodegradable, and compostable plastic. However, at the time of writing, no target has been published.

Paper and card

The Environmental Improvement Plan published in January 2023 sets a paper and card waste reduction target of 26% per person by 2028.

Of the targets identified above, the targets for plastics and paper and card refer to a reduction of materials in residual waste. The interventions and policies to be employed to achieve these targets will mostly promote the diversion of plastics, paper, and card from the residual stream into recycling streams rather than the overall reduction of material arisings. This diversion would not impact the composition of overall waste. One exception is the single-use plastics ban, which will result in some replacement of plastics with other materials (e.g., plastic cutlery will be replaced with wooden cutlery), and some waste reduction through the replacement of single-use products with reusable products. Both impacts could result in changes to the overall waste composition, however, since single-use plastics only account for 1% of total waste quantities[34], the impact is not considered to be significant. In contrast, the Courtauld Commitment target for food waste relates to a significant reduction in overall food waste arisings.

2.2.2.3 Compositions from Similar Countries

Comparable OECD countries such as Germany, France, Netherlands, and Ireland all have different purchasing habits and policies compared with England. These differences translate into different waste compositions. These variations in waste compositions were not used to forecast actual composition trajectories for England, but instead to explore a range of feasible possibilities, since they represent realities in comparable countries.

The countries were compared using a consistent dataset (Eurostat[35]). Using Eurostat data minimises the risk of using different composition calculations by countries not regulated by one body. A study by the European Commission[36] found Eurostat waste generation data to be comparable across countries reported. It is requested that countries collect their data according to the European list of waste within the EWC-Stat codes and there is a subsequent validation process. From the tonnages reported on Eurostat, waste composition was calculated and compared.

The composition-focussed forecasting scenario examines a change in the proportion of food, paper and cardboard and plastic waste based on the comparable countries. The compositions of all other waste materials were proportionally kept constant, relative to one another.

2.2.2.4 Composition Scenarios Analysis

To examine how changes to waste compositions may affect net-zero pathways, Ricardo has modelled low and high food, paper and cardboard and plastic waste scenarios in the following manner.

Low waste composition scenario

1. Examine food, paper and cardboard and plastic waste composition in the UK and comparable OECD countries on Eurostat and identify the countries with the lowest proportion of food, paper and cardboard, and plastic waste in its waste arisings.
2. Calculate the ratio of the proportion of food, paper and cardboard and plastic waste in the UK with proportion of each key waste material in the country identified in Step 1.
3. Apply the ratio calculated in Step 2 to the Baseline waste composition to identify a lower bound for the proportion of each key waste material in the UK.

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[33] https://www.gov.uk/government/publications/environmental-improvement-plan

[34] Single-use plastics account for 40% of all plastics (Single-Use Plastics Explained – Plastic Pollution Coalition (plasticpollutioncoalitionresources.org)) and plastics account for 2% of total waste arisings (see baseline assessment)

[35] https://ec.europa.eu/eurostat/databrowser/view/ENV_WASGEN/default/table?lang=en&category=env.env_was.env_wasgt

[36] https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1583142241609&uri=CELEX:52020DC0054

High waste composition scenario

1. Examine food, paper and cardboard and plastic waste composition in the UK and comparable OECD countries on Eurostat and identify the comparable country with the highest proportion of food waste in its waste arisings.
2. Calculate the ratio of the proportion of each key waste material in the UK with proportion of corresponding waste in the country identified in Step 1.
3. Apply the ratios calculated in Step 2 to the Baseline waste composition to identify a higher bound for the proportion of each key waste material in the UK.

Note: waste composition data from other countries such as USA were also examined but were not used for the development of the composition forecast because the methods of measurement were not directly comparable with the UK's methods of waste measurement. The Eurostat dataset employs the most consistent approach to measurement across countries[32] and has thus been used for analysis and scenario development.

The analysis examined the 'Generation of Waste' dataset, examining the quantities of 'Animal and mixed food waste', 'Paper and cardboard waste' and 'Plastic waste' against 'Total generated waste' to determine the relative proportions of each material. The proportions of food, paper and cardboard and plastic waste are all relatively low values because there are significant amounts of soil, aggregates and other waste materials that comprise significant proportions of a country's total waste arisings.

The results of the analysis are shown in Figure 8 to Figure 10.

Figure 8: Animal and mixed food waste proportion amongst comparable EU countries, 2012 to 2018

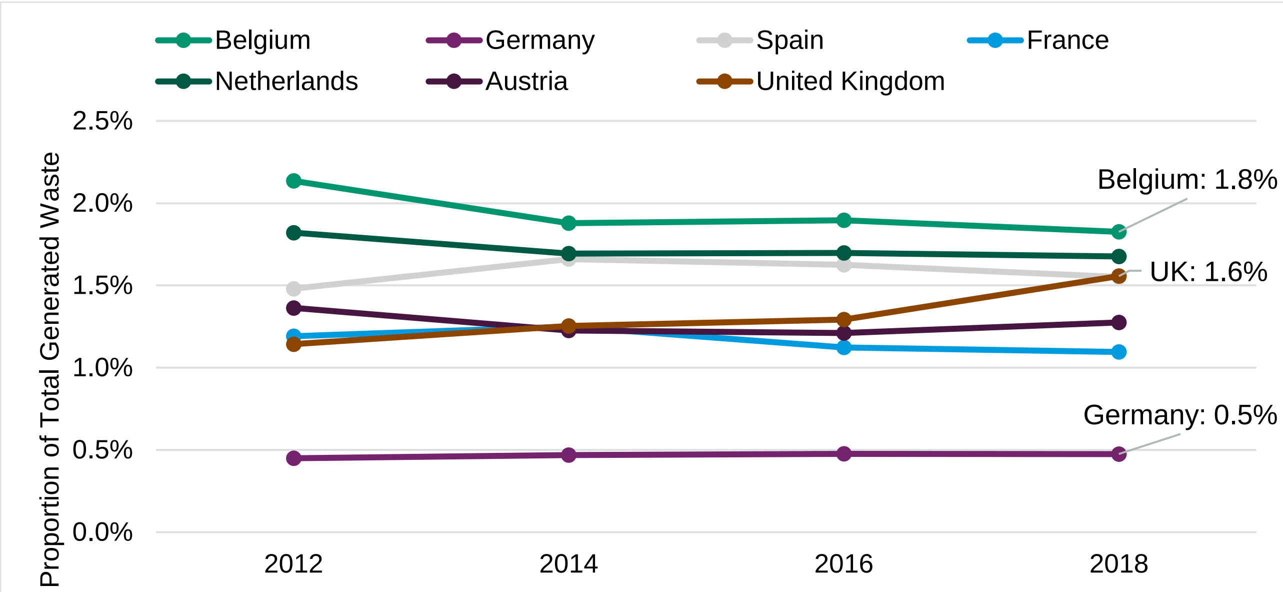


Figure 9: Paper and cardboard waste proportion amongst comparable EU countries, 2012 to 2018

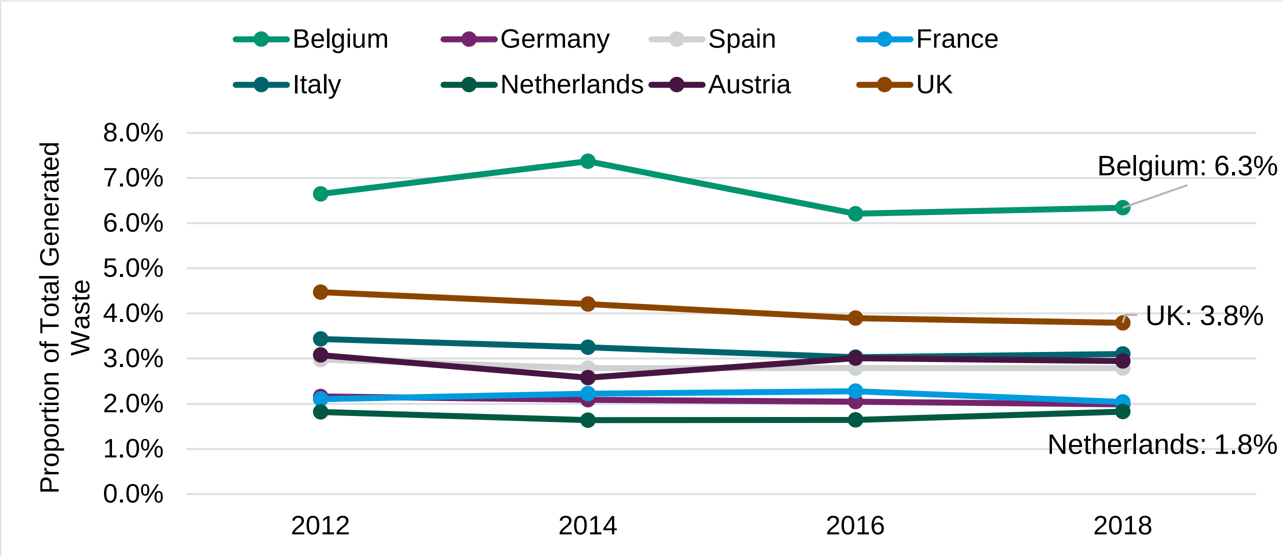
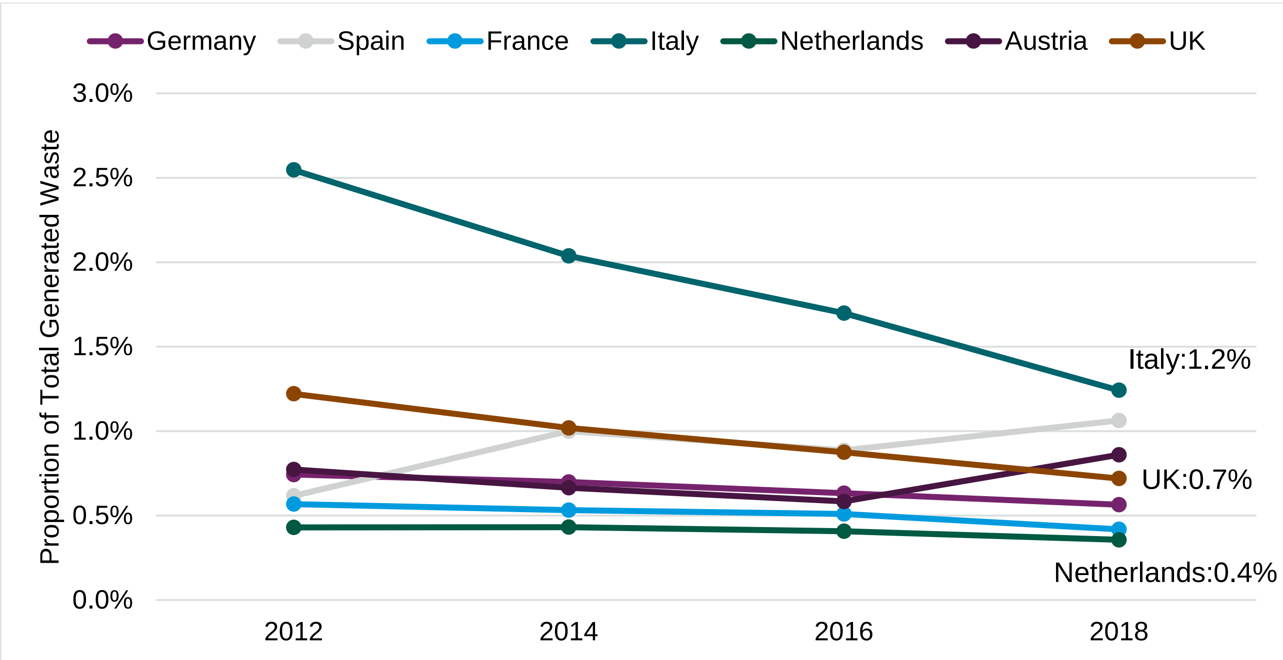


Figure 10: Plastic waste proportion amongst comparable EU countries, 2012 to 2018



From the analysis, the countries outlined in Table 4 below were identified as comparable countries with the lowest and highest proportions of waste on which to base the waste composition forecast.

Table 4: Summary of countries with high and low comparable proportions of waste

Waste material	High	Low
Food	Belgium	Germany
Paper and cardboard	Belgium	Netherlands
Plastic	Italy	Netherlands

Since the analysis was based on a different dataset (ENV23[37]), the ratios of the relevant country's proportions to the UK's proportion of waste on were then applied to this project's Baseline waste composition. This allowed the calculation of lower and upper bounds. The upper and lower composition scenarios are outlined in Table 5.

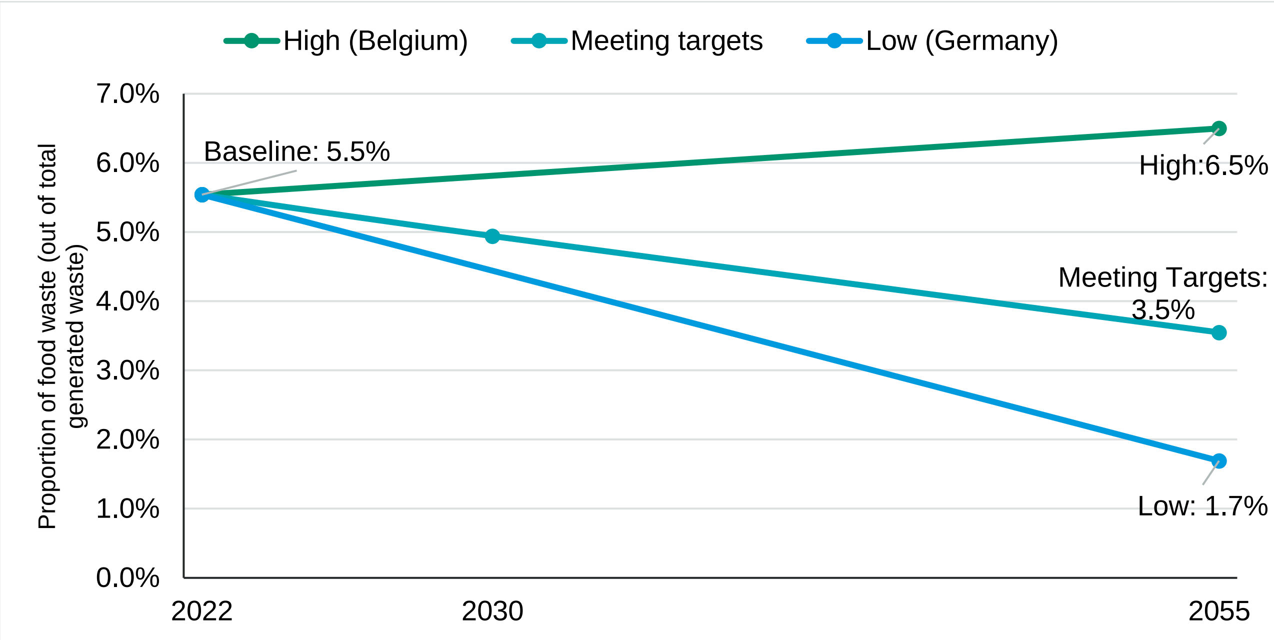
Additionally, the composition of waste before and after disaggregation (see section 2.1.1) was analysed. There was a slight difference in composition, however this was marginal. While the Eurostat is not disaggregated in the same manner, this data was only used to examine the relationship between different countries across the same dataset. Following this, the ratio proportions (UK to each selected country) for each of the key materials were applied to our disaggregated baseline data.

Table 5: Summary of lower and upper bound for waste proportions by material

Waste material	2022 Baseline	2055 Upper limit	2055 Lower limit
Food	5.5%	6.5%	1.7%
Paper and cardboard	4.1%	6.8%	2.0%
Plastic	2.5%	4.3%	2.0%

The results are shown in, Figure 11 to 13 which also shows the calculated proportion of food waste required to meet the targets mentioned in section 0. This is included for contextual purposes; scenario development has not been based on future policies.

Figure 11: Food waste proportion forecast



[37] https://www.gov.uk/government/statistical-data-sets/env23-uk-waste-data-and-management

Figure 12: Paper and cardboard waste proportion forecast

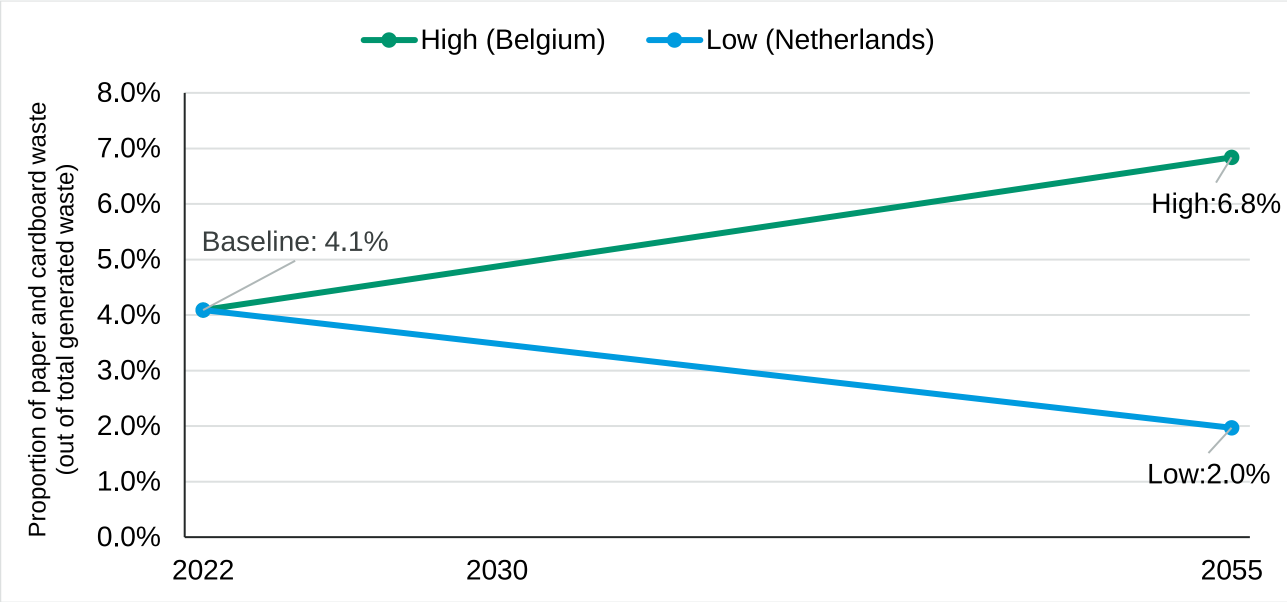
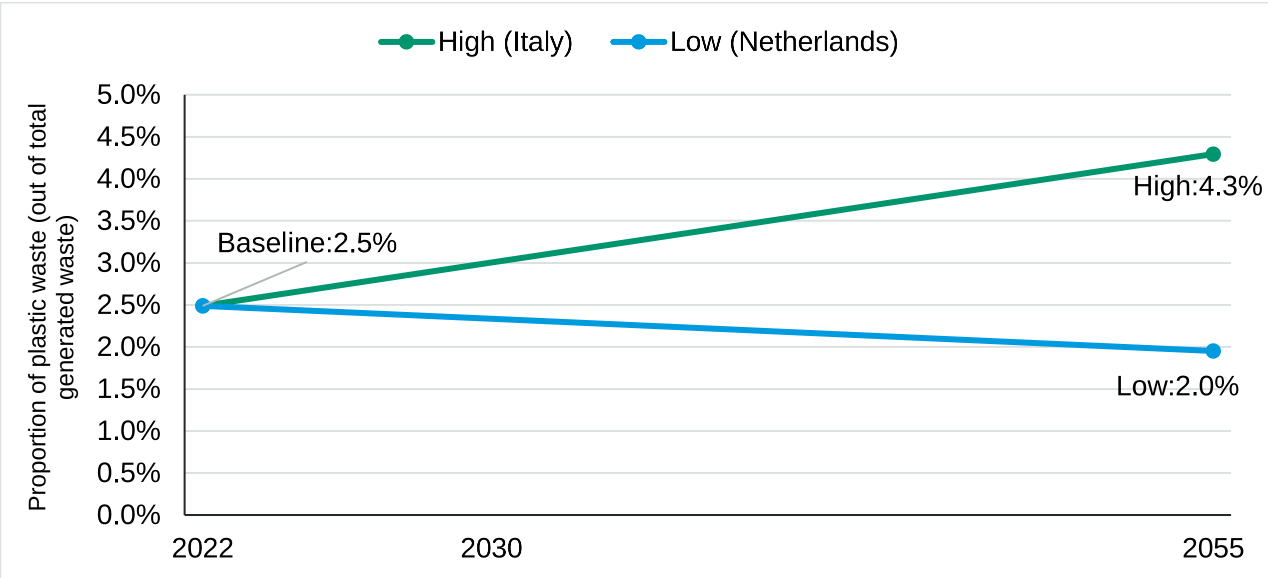


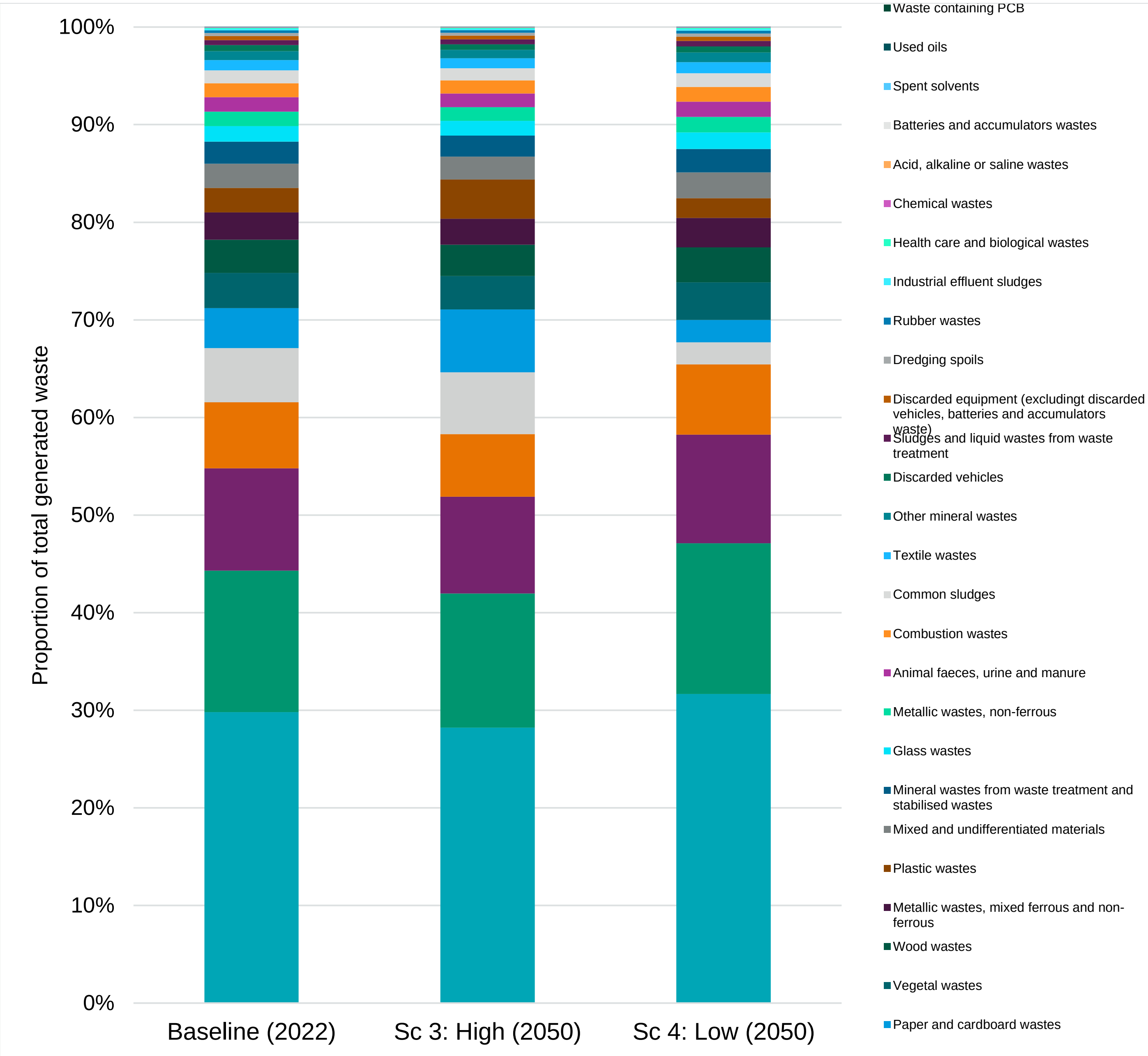
Figure 13: Plastic waste proportion forecast



2.2.2.5 Composition Scenarios Results

Total waste composition scenarios calculated using the food, paper and cardboard and plastic waste forecasts are shown in Figure 14 and compared with the baseline waste composition. The figure reflects the proportional changes in the other materials forecast to account for the changes in the key materials.

Figure 14: Total waste composition scenarios



2.2.3 Events and forces that could impact scenarios

There are several events and forces that could result in the future waste arisings and compositions falling well outside the bounds described by the scenarios. However, it is difficult to predict the impacts of these events on waste, and when or how often they could occur during the forecasted period. The NIC approach to managing uncertainty[38] can be referred to when looking to understand the likelihood of future events and their impact on infrastructure.

There are several unpredictable events and forces that would affect waste quantities and compositions. Some of these are listed below:

- Long-term recessions
- Climate change
- Resource scarcity

[38] https://nic.org.uk/app/uploads/Managing-Uncertainty-May-2022.pdf

- Significant population changes
- Significant changes to the distribution of wealth
- Natural disasters
- Wars/conflict

2.3 NET ZERO PATHWAYS

2.3.1 Data Inputs

The baseline assessment and forecasting analysis provides the input data for the NZP Model to examine the net zero pathways for the four scenarios:

1. Scenario 1: High Arisings
2. Scenario 2: Low Arisings
3. Scenario 3: High Arisings + High Composition
4. Scenario 4: Low Arisings + Low Composition

For each of the four scenarios identified above, the NZP model calculated how the following variables change from the baseline year (2022) to 2055:

4. Carbon emissions (CO2e)
5. Costs
6. Recycling rate

These calculations will use the model inputs, assumptions and user inputs discussed below. Calculation details are provided in Table 6.

Table 6: NZP Model Calculations

Variable	Calculation Method
Carbon Emissions	For each [waste material × destination] combination, the quantity of waste is multiplied by the relevant emission factor to determine the associated carbon emissions.
Costs	For each destination (facility type), the quantity of waste is multiplied by the relevant cost-per-tonne to determine the total cost of waste management.
Recycling Rate	Recycling rate assumptions for each [waste material × destination] combination are multiplied by the respective quantities of materials going to each destination.

2.3.2 Method

Once the model was set up with the inputs from the waste forecasting process, Ricardo adjusted the apportionment of waste materials to destinations to meet (or approach) the targets and goals specified in Table 6.

Ricardo then examined the model outputs and used a manual, iterative process of amending the proportions of waste to each destination to explore NZPs. This process was not automated due to the complexity of balancing several variables (technical feasibility, practicability, future policy) as well as objectives (lowest carbon emissions, lowest cost). Further details are provided in section 2.3.2.1. Following the development of each NZP, the models went through a quality assurance process. This process included verification of the formulas and confirmation of the validity of the assumptions and inputs.

2.3.2.1 Destination Selection

The model requires the user to input the proportion of waste going to each destination (facility type) in the future. The user can amend these proportions by entering a proportion (%) for each [material × facility type] combination. The total proportion must equal 100% and the model will flag if this is not the case.

This variable has not been automated, but left as a user input, there are several factors to be considered in the apportionment of materials to destinations, i.e.:

1. Is it technically feasible for the waste to be accepted by the facility type? (e.g., metals cannot be processed at an anaerobic digestion facility).
2. Is it practical for the waste to be managed via the facility type? (e.g., how much mixed and undifferentiated waste can be separated and recycled?).
3. What are the future policies and trends to consider? (e.g. waste to landfill will likely reduce).

2.3.3 Assumptions

2.3.3.1 Calculations

The model relies on two sets of assumptions for its calculations:

1. **Carbon Emission Factors**: The model uses the carbon emission factors developed as part of the baseline assessment to determine the carbon emissions associated with the treatment, processing and disposal of each waste material in each facility type. These emission factors only represent scope 1 emissions, to not overlap with NIC's work with the energy sector. The emission factors are provided in Appendix 1 - Table A 1.
2. **Recycling Rate Assumptions**: Ricardo has developed a set of recycling rate assumptions for each [material × facility type] combination based upon industry experience, to provide a proxy for the actual recycling rate for the purpose of examining how the overall recycling rate may change for each pathway. Further details are provided in section 2.5. Assumptions are provided in Appendix 1 - Table A 2.

While the carbon emission factors only represent scope 1 emissions, emissions from scopes 1 and 2 have been considered in the approach taken, to align with the methodology for national targets. Table 7 summarises the main sources of emissions from each facility type, disaggregated by scope. This table provides insight into how net zero pathways can look different depending on the scope(s) considered. To summarise the emissions reduction approaches:

- Scope 1: reduce waste to landfill and EfW, increase recycling.
- Scopes 1 and 2: as above plus prioritising energy efficient recycling processes.
- Scopes 1, 2 and 3: as above plus prioritising local recycling processes (minimise transport).

Inclusion of avoided: includes benefits from the use of recyclate.

Table 7: Emissions Sources per Facility Type

<table>
<tr><th>Facility Type</th><th>Scope 1 (considered in this analysis)</th><th>Scope 2</th><th>Scope 3</th><th>Avoided</th></tr>
<tr><td>Energy from Waste (EfW) and Advanced Thermal Treatment (ATT)</td><td>Direct CO_2 (Combustion)</td><td rowspan="2">Fuel and electricity used (site equipment and operations)</td><td rowspan="2">Transport, purchased goods and services, use of sold products, employee commuting, investments, leased assets.</td><td>Substitution of fossil-fuel-sourced electricity</td></tr>
<tr><td>Material Recycling Facility</td><td>None</td><td>Substitution of virgin materials with recycled materials (extraction, manufacturing emissions)</td></tr>
</table>

<table>
<tr><th>Facility Type</th><th>Scope 1 (considered in this analysis)</th><th>Scope 2</th><th>Scope 3</th><th>Avoided</th></tr>
<tr><td>Other Bulking</td><td></td><td rowspan="5"></td><td rowspan="5"></td><td rowspan="2">None</td></tr>
<tr><td>Landfill</td><td rowspan="4">Direct CO_2 and CH_4 (Fugitive emissions)</td></tr>
<tr><td>Mechanical Biological Treatment</td><td rowspan="3">Substitution of fossil-fuel-sourced electricity</td></tr>
<tr><td>Composting</td></tr>
<tr><td>Anaerobic Digestion</td></tr>
</table>

2.3.3.2 Policies

The pathway scenarios include the application of several published policies and targets relevant to the priority materials. The policies and targets aim to see a reduction in generation of waste and improvement of recycling rates, which will impact the quantities of waste designated to each facility type. The proportions of the priority materials modelled were adjusted to meet the relevant policy/target. The policies and targets considered are outlined in Table 8.

Table 8: Legislative scope and modelling actions

Name	Target	Modelling
Net Zero Strategy[39]	Net zero by 2050.	Emissions reduced as much as possible using practical assumptions. 1. Reduce overall waste to landfill from C&I and LACW sources by 40% in 2035, C&D by 30% 2. Reduce overall waste to landfill from C&I and LACW sources by 90% in 2050, C&D by 80%.
Sixth Carbon Budget[40]	Move waste from EfW to EfW with Carbon Capture and Storage.	Move waste from EfW (without CCS) to EfW with CCS. 1. 10% of EfW tonnes in 2030 2. 40% of EfW tonnes in 2040 3. 90% of EfW tonnes in 2050
Defra Targets[41]	Zero avoidable plastic waste by 2042.	Set 'plastic waste' to landfill at 0% in 2050 and proportionally increase the amount to MRF.
Defra Consultation[42]	Recycle 65% of municipal waste by 2035.	Aimed for through overall reductions in municipal waste to landfill/incineration - diverting to other 'recycling' facilities (MRF/AD/Composting)

[39] BEIS (2019) Net Zero Strategy https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1033990/net-zero-strategy-beis.pdf

[40] Climate Change Committee (2020) https://www.theccc.org.uk/wp-content/uploads/2020/12/Sector-summary-Waste.pdf

[41] Defra (2021) https://www.gov.uk/government/news/next-steps-to-tackle-plastic-waste

[42] Defra (2022) Resource efficiency and waste reduction targets: Detailed Evidence report. https://consult.defra.gov.uk/natural-environment-policy/consultation-on-environmental-targets/supporting_documents/Resource%20efficiency%20and%20waste%20reduction%20targets%20%20Detailed%20evidence%20report.pdf

Name	Target	Modelling
	50% reduction in residual waste to landfill and incineration by 2042.	1. 'Sorting residues' sent to EfW from C&I residual waste set as 20% in 2035, 5% in 2050. 2. Achieved for LACW residual waste through overall reductions to landfill and EfW 3. Reduce overall waste to EfW from C&I and LACW sources by 10% in 2035, 30% in 2050.
	Near elimination of biodegradable municipal waste to landfill by 2030.	Set the following waste types to landfill to 0% in 2035 for both C&I and LACW: 'animal and mixed food waste' 'paper and cardboard wastes' 'vegetal wastes' 'animal faeces, urine and manure' 'textile wastes' 'wood' wastes' Animal and mixed food is proportionally increased in AD, the others to MRF

2.4 COST MODELLING

2.4.1 Methodology

The challenge with calculating the infrastructure cost of processing a given tonnage of waste in a certain way is that the waste industry is mature, and therefore individual facilities are continuously being developed and reaching the end of life to be decommissioned. As a result, it is not possible to establish the cost of capital as one might for a single asset, assuming a certain capital expenditure period of 1 to 3 years and then working on a payback period. This is as capital is constantly being spent when viewing waste treatment infrastructure at a national level. As a result, Ricardo needed to find a simple methodology of calculating the steady state cost of capital on the basis that constant investment is occurring to maintain the required capacity.

To do this the overnight capital cost per tonne was identified for capex, and an opex cost was provided based on 2022 figures. Costs were compiled based on both publicly available information on the cost of facility development and operation, and industry intelligence gathered by Ricardo through involvement with a range of waste sector development projects. A range of facilities were looked at, and an indicative cost per tonne was calculated based upon the permitted tonnage for the facility and the cost of development. These were then averaged to provide a single value. For simplicity the financing period and repayment period were both assumed to be the same as the predicted lifespan of the facility of 33 years.

Due to the wide range of facilities within the scope of the study, and the unique features which influence the cost of development of any project (for example geographic features (e.g. water courses, mine shafts etc.), transport costs for staff and materials based on site location, economies of scale and more) Ricardo have provided all costs to a Class 5 classification of project definition[43]. This provides an expected accuracy range of -50% to +100%.

Costs are in nominal terms (including inflation) and do not include taxes or subsidies as this would be dependent on complex factors unique to the facility such as when it was built (and hence eligibility for subsidies), feedstock, outputs and more. A repayment period was input based on the expected lifespan of the facility.

[43] 18R-97: Cost Estimate Classification System - As Applied in Engineering, Procurement, and Construction for the Process Industries (costengineering.eu)

The Commission provided Ricardo with a spreadsheet outlining the expected Weighted Average Cost of Capital (WACC), which also contained the anticipated CPI rate of inflation which we used to compute the annuities for an investment in a specific year, covering the entire repayment period. To determine the annuity, we combined the inflated capital cost for each year with the anticipated payback period and WACC for each year. We assumed the same repayment period every year for all investments. Regarding opex, we took the initial value in 2022 and multiplied it by the forecasted inflation rate for each subsequent year.

2.4.1.1 Least Cost Pathways

It was intended that the modelling would examine a pathway to achieve net zero emissions, then explore sensitivities (i.e., different infrastructure mixes) to reduce costs, to find the least cost net zero pathway (LCNZP). However, as the results indicate in section 3, it was not possible to achieve net zero emissions therefore, the assumptions used to achieve the lowest possible emissions Table present the most realistic pathway for emissions reductions. For this reason, cost sensitivities were not modelled.

2.4.2 Assumptions

Due to the wide range of approaches to waste treatment, financing of facilities, age of existing facilities and other factors a number of assumptions have been made to simplify the cost modelling. Key assumptions are as follows:

- Capex covers the cost of facility development including civils and ground works, structural works, process design, installation, and commissioning. It excludes the cost of purchasing the land.
- Opex covers the cost of operating the facility, including staffing, utilities, consumables, spares, maintenance, mobile plant operation and overheads. Excluded are the revenues and costs generated from the disposal of any products and residues from the process. The reason for this is that those costs are highly variable depending on market forces, disposal arrangements unique to each site, and the quality of the output materials produced. A projection of the revenues and costs of sale/disposal of key output products has been provided. See section 2.4.3 for more detail.
- Profit margin has also been excluded from capex. Every operator will have its own expectation of profit margin depending on its own operating model and corporate strategy. Profit margin will also be set to an extent by the cost of operating the facility against the benchmark gate fee available in the local area. The localised gate fee will in turn be a product of the number of similar facilities within a certain radius (and consequently competition), availability of target waste material or geographic location and associated costs (for example higher staff costs in London and South East than in the North).
- Taxes and subsidies have been excluded from the costing. Taxes incurred as a result of the feedstock accepted (such as landfill tax) will be passed through directly to the government and consequently the owner/operator will not gain any benefit from that. Subsidies differ and are time dependent – older facilities will have legacy access to subsidies that new facilities are not eligible for (for example Renewable Obligation Certificates for green energy generators). Therefore, trying to standardise applicable subsidies across a national portfolio of pre-existing waste processing assets is complex and beyond the scope of this report.
- Financing and repayment period has been assumed to be the same as the facility lifespan for the sake of the calculations.

2.4.3 Revenue streams and disposal costs

Any waste processing facility will have costs associated with the sale or disposal of its output products and residues. These are many and varied, with a great many factors impacting the revenue generated. Some of the key outputs and factors affecting their value are set out below:

- Electricity. Some types of waste treatment facilities may generate electricity including EfW facilities, AD facilities and ATT facilities. These will use the electricity to power the facility first, and export excess to the local grid. The revenue generated from the sale of electricity will track national and international energy prices and so can be unpredictable. Furthermore, operators will often hedge the sale price, fixing the revenue from the sale of generated electricity for a period into the future. These factors make it hard to forecast the revenue generated from electricity sale.
- Recyclables. Material Recycling Facilities (MRFs) will tend to produce output products which may be sold for further treatment and to be recycled. However, the process steps followed, and the products produced differ from plant to plant. For example, one facility may produce a mixed dense plastic line

which is sold at a low value to a plastic recycling plant for further sorting, while another might separate the plastics out by type (for example PET, HDPE, PP etc.). These segregated single-stream plastics will have a higher value when sold on. This is true for all plant outputs. When combined with the fact that prices of recyclables are impacted by global commodity prices (plastics, paper, metals, cardboard etc.) this results in a variable and unpredictable revenue stream.

A final complication is that in the case of many dry mixed recyclable MRFs, operators may operate a 'gain share' model whereby the gate fee charged to the feedstock supplier is variable depending on the revenue generated from the sale of the product. This arrangement is unique to each facility and is hard to forecast.

- Compost/fertiliser. AD and composting plants will produce a compost or fertiliser following the biological degradation of the incoming feedstock. The allowable fate of this material is dependent on the input feedstock to the plant. Compost derived from parks and gardens waste can be treated and deployed to land with little issue. Organic waste containing animal by-products (i.e., food waste including meat) needs to be pasteurised before the resulting compost can be deployed to land. Pasteurisation involves elevating the temperature of the material for a set period of time to ensure that any pathogens present in the material are destroyed. Finally organic waste derived from a mixed waste source cannot be used as a fertiliser and is only suitable for land remediation schemes. Therefore, an income may be generated from organic materials which are permitted to be used as a fertiliser, whilst there is usually a disposal cost associated with sending non-compliant organic material for land restoration.

  A further complication is that many farmers do not want fertiliser during the winter months when it is wet and there is a risk of the organic material running off the land into water courses and polluting the environment. Therefore, there may be seasonal fluctuations in the revenue for fertilisers, with that produced in winter needing to be stockpiled at site or disposed of at cost.

These examples illustrate the difficulty of applying blanket revenue and cost figures for output products across the industry. In agreement with NIC Ricardo have looked back at historic revenue/costs associated with key output products and used them to forecast some likely revenues/costs, and these have been provided separately. These have been decoupled from the cost modelling to avoid introducing inaccurate figures that could skew the data.

2.5 RECYCLING RATE MODELLING

Baseline material recycling rates were calculated using the full set of WDI data, relying upon activity code information logged in WDI (i.e., recovery codes R3, R4 and R5). Pathway modelling used a different method of calculating recycling rates, as it is not possible to predict the quantity of waste that will be classified as R3, R4 or R5 recovery codes. The method involved compiling a set of material recycling assumptions for waste entering each facility type, then applying these assumptions to the modelled future quantities that are estimated to be sent to each facility type. The material recycling assumptions for each facility type are provided in Appendix 1 – Table A 2.. These assumptions are based on Ricardo's industry experience.

This method provides a high-level approximation or a proxy for each material recycling rate. Since the assumptions and the method are kept consistent across future years and all pathways, the results can be used to provide an indication of the scale and direction of change of the recycling rate based on the quantities of waste sent to each facility type in the future.

2.6 ENHANCED CIRCULARITY PATHWAYS

2.6.1 Data Inputs

The baseline assessment and forecasting analysis provides the input data for the NZP Model to create four different future scenarios. These consist of two scenarios focusing on future potential waste arisings, and two scenarios also factoring in differences in waste composition:

1. Scenario 1: High Arisings
2. Scenario 2: Low Arisings
3. Scenario 3: High Arisings + High Composition

4. Scenario 4: Low Arisings + Low Composition

For each of the four scenarios identified above, the Enhanced Circularity Pathways (ECP) model calculated how the following variables change from the baseline year (2022) to 2055:

5. Environmental impact categories (global warming potential, acidification, eutrophication, freshwater aquatic toxicity, human toxicity, and depletion of abiotic resources).
6. Costs
7. Recycling rate

These calculations will use the model inputs, assumptions and user inputs discussed below. Calculation details are provided in Table 9Table 6.

Table 9: ECP Model Calculations

Variable	Calculation Method
Carbon Emissions	For each [waste material × destination] combination, the quantity of waste is multiplied by the relevant emission factor to determine the associated carbon emissions.
Acidification	For each [waste material × destination] combination, the quantity of waste is multiplied by the relevant emission factor to determine the associated acidification emissions.
Eutrophication	For each [waste material × destination] combination, the quantity of waste is multiplied by the relevant emission factor to determine the associated eutrophication emissions.
Freshwater aquatic toxicity	For each [waste material × destination] combination, the quantity of waste is multiplied by the relevant emission factor to determine the associated freshwater aquatic toxicity emissions.
Human toxicity	For each [waste material × destination] combination, the quantity of waste is multiplied by the relevant emission factor to determine the associated human toxicity emissions.
Depletion of abiotic resources	For each [waste material × destination] combination, the quantity of waste is multiplied by the relevant emission factor to determine the associated depletion of abiotic resources.
Costs	For each destination (facility type), the quantity of waste is multiplied by the relevant cost-per-tonne to determine the total cost of waste management.
Recycling Rate	Recycling rate assumptions for each [waste material × destination] combination are multiplied by the respective quantities of materials going to each destination.

2.6.2 Priority Materials

Priority materials identified for circularity were evaluated based on:

- Waste quantities sent to project facilities (Landfill, Material Recycling Facility (MRF), Other Bulking, Composting, Anaerobic Digestion (AD), Advanced Thermal Treatment (ATT), Mechanical Biological Treatment (MBT), Energy from Waste (EfW), Recycling).
- Raw volume quantities, where known. Bulk densities were used to convert the waste arisings to raw material volumes. For some streams, the bulk density was not known, as the categories are broad and limited research has been undertaken by organisations such as WRAP, DEFRA or SEPA. Where

known, bulk densities have been sourced from WRAP's Kerbside Analyser (KAT) Tool and WRAP's Bulk Density report[44].

- Recovery rate. Waste related activities are classed as recovery or disposal as defined by the EU Waste Framework Directive. The recovery rate includes the R1 to R13 recovery options.
- Environmental impacts associated with processing, values reported on a per tonne basis. These include burdens that occur because of the processing but include the avoided burdens that occur when materials and energy are recovered from the waste, which are represented by negative values. When the avoided burdens exceed the burdens, an overall negative value is calculated.
- Environmental impacts of raw materials, as sourced from SimaPro 9.4 and Ecoinvent 3, using the CML-IA baseline V3.08 / EU25 impact assessment method[45].
- Environmental impacts that could be avoided with additional recycling, with the values reported on a per tonne.
- Technical potential for increasing recycling: Evaluated using a Red (1), Amber (2), Green (3) assessment, based on the ability to increase recycling above current levels, with (1) limited technological potential, (2) some technological potential and (3) significant technological potential.
- Market potential for increased recycling: Evaluated using a Red (1), Amber (2), Green (3) assessment, based on the average demand for the outputs of the recycling process of each material category, considering potential future policy changes. With (1) limited market potential, (2) some market potential and (3) significant market potential.

This assessment was presented to NIC to decide the priority waste streams, with the following five materials taken forward:

- **Animal and mixed food waste**: Food waste has a low recycling rate, high market potential and significant environmental impacts associated with the production of food, hence there is potential to increase circularity in this stream with great environmental benefits.
- **Discarded equipment** (excluding discarded vehicles, batteries and accumulators waste): Discarded equipment has increased market potential, due to the mixture of valuable resources within the waste stream, and the significant environmental impacts associated with its manufacturing and its components.
- **Paper and cardboard wastes**: Paper and cardboard waste has high waste arisings, increased market potential and a high environmental impact of production, hence increasing its circularity would provide environmental benefits.
- **Plastic wastes**: Plastic wastes have high waste arisings, increased market potential and high raw materials impacts, hence increasing their circularity would provide environmental benefits.
- **Textile wastes**: Textile wastes have significant environmental impacts associated with their production and low recycling rate, hence increasing circularity for this stream should be prioritised.

2.6.3 Method

The Enhanced Circularity Pathways (ECPs) explore the cost and environmental impacts of increasing the recycling rates of the selected priority waste materials to three different peak values (low, medium, high).

The low, medium and high peak recycling rate assumptions were based on the results of the NZP modelling, as each NZP scenario resulted in a different uplift of the material recycling rates to achieve Net Zero.

Each ECP assumption has been determined considering:

- Current (baseline) recycling rate.
- Peak NZP recycling rate (i.e. the highest recycling rate value for that material in the NZP scenario).

[44] WRAP (2010) Material Bulk Densities Summary Report. https://wrap.org.uk/sites/default/files/2021-02/WRAP-bulk-density-summary-report-Jan2010.pdf

[45] PRé Sustainability (2022). SimaPro database manual. https://simapro.com/wp-content/uploads/2022/07/DatabaseManualMethods.pdf

- Anticipated future trends for the management of the waste material based on policies mentioned in Section 2.6.7.2, Table 8 and in further detail in Ricardo's Policy Effectiveness Report.

Table 10 presents the baseline recycling rate for each of the five priority waste materials, as well as the peak recycling rate range from the NZP scenarios (purely as a reference). Alongside these values are the low, medium and high peak recycling rate assumptions for the purpose of modelling each ECP.

The recycling rate assumptions are outlined in Table 10 below:

Table 10: ECP Recycling Rate Assumptions

Priority Material	Recycling Rate				
	Baseline (2022)	NZP Peak Range	ECP Low Peak	ECP Medium Peak	ECP High Peak
Animal and mixed food waste	35%	65%	70%	75%	80%
Discarded equipment (excluding discarded vehicles, batteries and accumulators waste)	50%	68% - 71%	75%	80%	85%
Paper and cardboard wastes	53%	75%	80%	85%	90%
Plastic wastes	33%	64%-65%	70%	75%	80%
Textile wastes	18%	35%	40%	50%	60%

2.6.4 User Input: Destinations

The user input is the same as that of the NZP model, see section 2.3.2.1 of this report.

2.6.5 Outputs

The model provided the following outputs for the three ECP levels for each of the four forecasting scenarios:

1. Carbon emission estimations for each examined year at the following levels of detail:
    - Total emissions.
    - Disaggregated into the three waste streams (construction and demolition waste, commercial and industrial waste, local authority collected waste).
    - Disaggregated into each material category shown in Section 2.3.
    - Disaggregated into each facility type shown in Section 2.3.
2. Quantity of waste, tonnes, at the same level of detail.
3. Costs per facility type.
4. Tabular and graphical outputs of the enhanced circularity pathway.
5. Tabular and graphical outputs of the mix of infrastructure.

2.6.6 Limitations and Exclusions

The model has the following limitations:

1. A maximum of nine facility types.
2. A maximum of four waste streams.
3. A maximum of thirty-two material categories.
4. A maximum of four forecasting scenarios.

The model has the following exclusions:

1. Calculation of emissions associated with waste collection and transfer.
2. Calculation of environmental impacts, other than GHG emissions.

2.6.7 Assumptions

2.6.7.1 Calculations

The model relies on two sets of assumptions for its calculations:

3. **Carbon Emission Factors**: The model uses the carbon emission factors developed as part of the baseline assessment to determine the carbon emissions associated with the treatment, processing and disposal of each waste material in each facility type. See Appendix 1 – Table A 1.
4. **Recycling Rate Assumptions**: The baseline recycling rate has been calculated using the complete WDI dataset of waste quantities and destinations, i.e., not the subset of waste quantities and facility types used for the baseline assessment. It is not possible to accurately calculate the recycling rate based only on the data included in the baseline assessment and the forecasting analysis, because some facility types are excluded and the included facility types are broad categories, which means there are large ranges in recycling rates even for the same facility type. For this reason, Ricardo has developed a set of recycling rate assumptions for each [material × facility type] combination. These assumptions have been developed using industry experience, then calibrated using the baseline assessment data, to provide a proxy for the actual recycling rate for the purpose of examining how the overall recycling rate may change for each pathway. See Appendix 1 – Table A 2 for the assumptions.

2.6.7.2 Policies

The policies applied to the ECP model are the same as those used within the NZP modelling, see section 2.3.3.2 of this report2.3.2.1.

3. NET ZERO PATHWAY RESULTS

3.1 TECHNOLOGY MIX OF INFRASTRUCTURE & CAPACITY

In 2055 it is expected that the total tonnage of waste in England will rise from the baseline year tonnage of 120Mt in 2022 to approximately 170Mt in the high scenarios 1 and 3, and 140Mt in scenarios 2 and 4, shown in Figure 15. Therefore, even under the low scenario assumptions, in 2055 at the end of the projected period, an approximate additional 20MT of waste will need managing in England.

Figure 15: Comparison of total waste arisings by scenario (excluding other bulking tonnes)

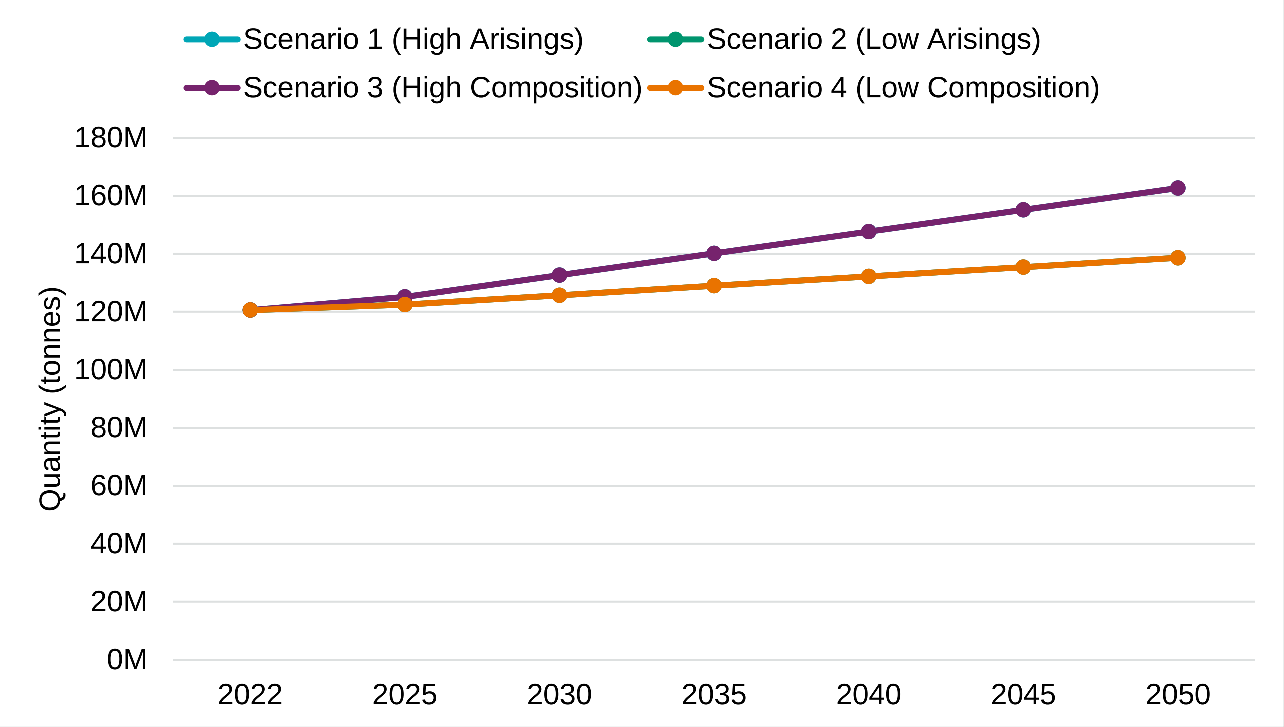


Figure 15 indicates that the projected tonnage is identical for scenarios 1 and 3 and for scenarios 2 and 4. This is because scenarios 1 and 3 both have high waste arisings assumptions, with scenarios 2 and 4 following low waste arisings assumptions as outlined in the methodology. The waste composition assumptions have not impacted on the waste quantity projections, but merely the makeup of the waste quantities.

The following Figure 16 to Figure 19 display the tonnages under each of the different scenarios and broken down by the proportions to each facility type. Each stacked column in the following figures represents the tonnages going to each given facility type. The total waste quantities increase over time within each scenario, as outlined in Figure 15.

Figure 16: Scenario 1 (High Arisings) Tonnes per facility type[46]

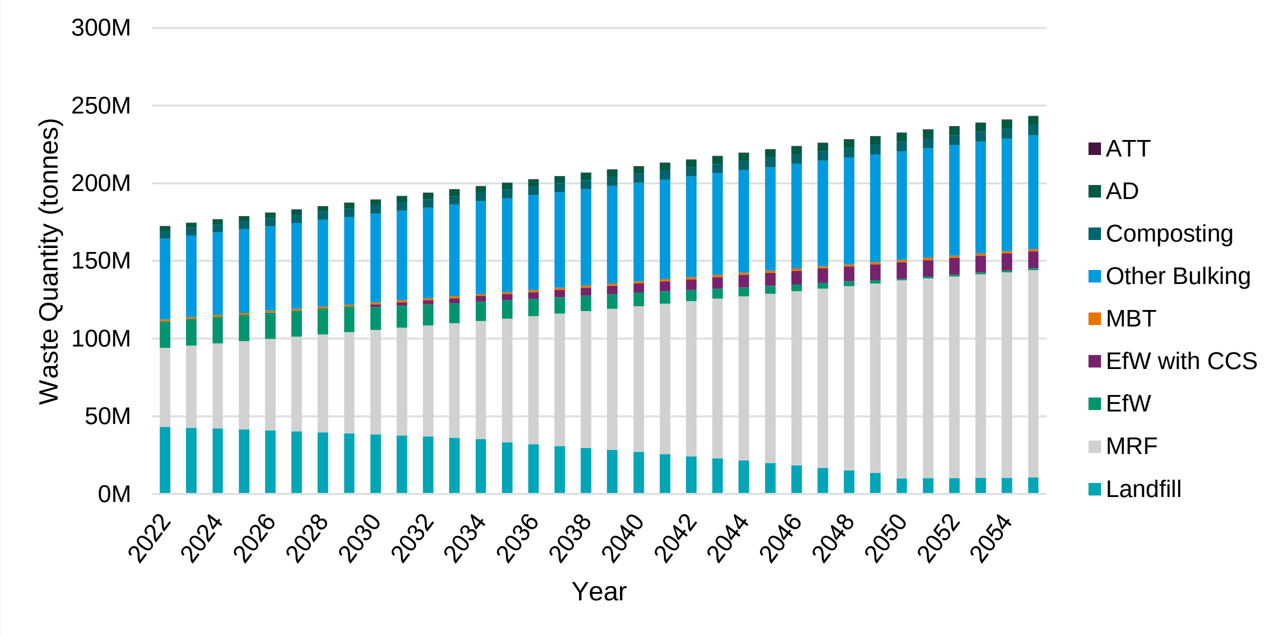
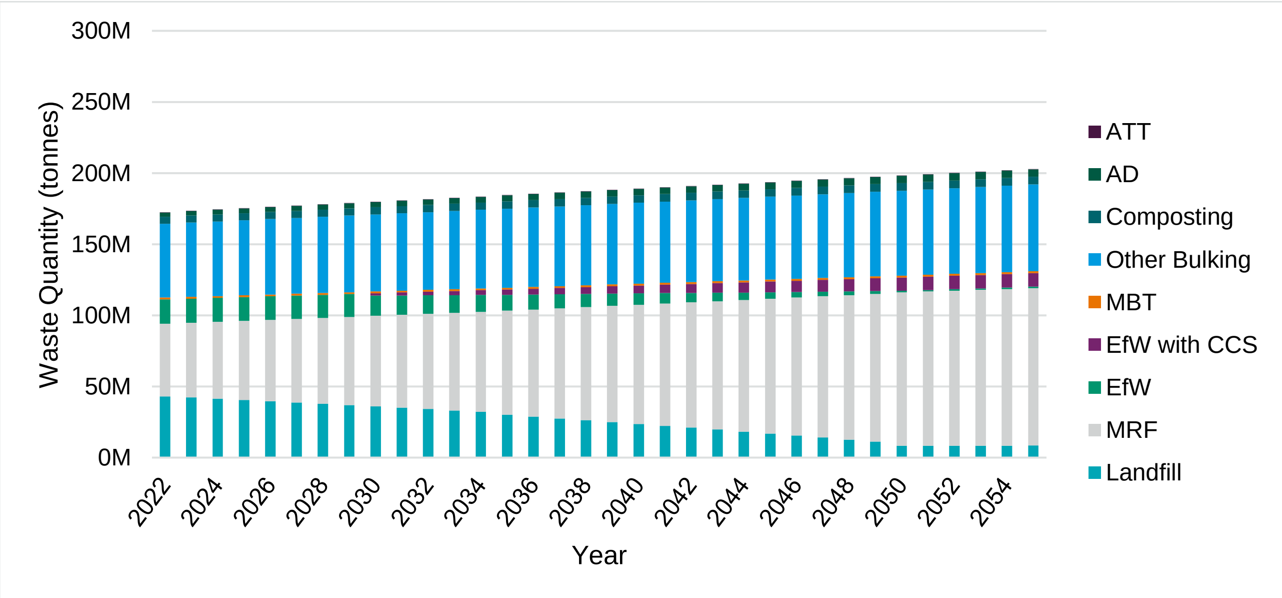


Figure 17: Scenario 2 (Low Arisings) Tonnes per facility type[46]



[46]The ‘MRF’ facility type represents all mechanical recycling as well as some other recycling streams. It also represents both primary sorting processes and secondary processes.

Figure 18: Scenario 3 (High Composition) Tonnes per facility type[46]

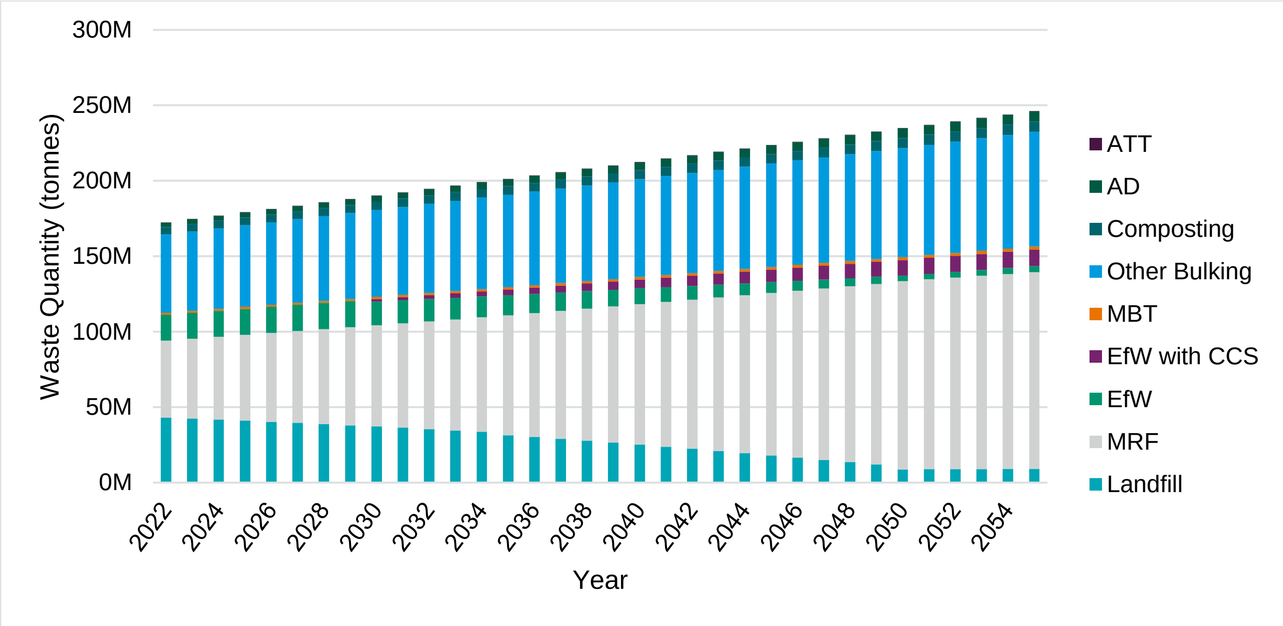
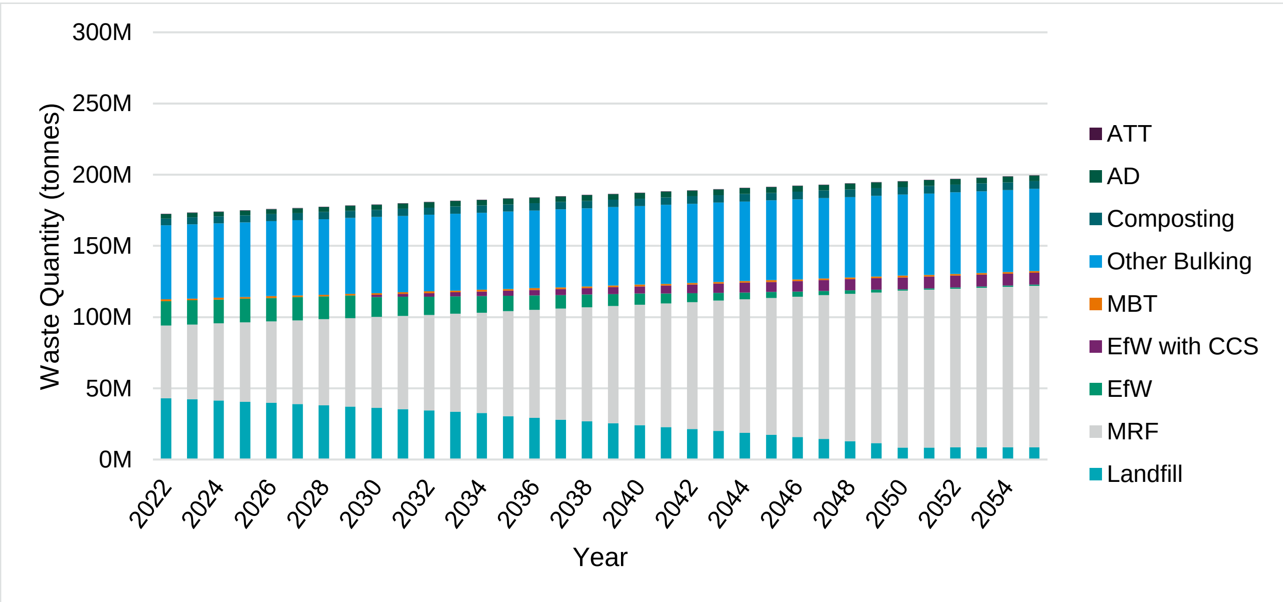


Figure 19: Scenario 4 (Low Composition) Tonnes per facility type[46]



Key discussion points to achieve the lowest emissions possible by the year 2050:

Material Recycling Facilities

The charts show that MRF capacity is likely to need to increase significantly, with tonnages sent to MRF increasing by approximately 150% in scenarios 1 and 3, and by 112% in scenarios 2 and 4. This increased capacity will be required to enable a greater quantity of materials to be diverted from landfill or EfW and recycled instead. The driver for the increase in capacity requirements is the policy commitments, outlined in the modelling assumptions. These result in the increased capture of more recyclable materials and the diversion of waste away from disposal, pushing it further up the waste hierarchy. A key aspect of this will be the success in extracting recyclable materials, such as plastic bottles and metal cans, from mixed residual waste streams.

However, there are several key factors to consider when interpreting the MRF data:

1. In the WDI 'MRF' is defined as a 'Material Recycling Facility'. As such the WDI does not consider a MRF to be a facility which simply processes Dry Mixed Recyclables (DMR), but any facility which uses

some form of mechanical treatment to process waste materials which does not fall into another treatment category (such as AD, composting, EfW etc.). As a result, some examples of facilities which fall into this treatment category are C&D waste processing plants, used cooking oil processing plants, AD preparation plants (i.e., de-packaging of food waste prior to onward transportation to an AD facility), composting pre-treatment and more. Even a simple bulking and baling operation could be classified as a MRF. This is highlighted in Table 11, showing the highest proportion of the forecasted waste to MRF is C&D waste. Therefore, the increasing requirement for MRFs won't necessarily be for complex recycling plants to treat DMR.

Table 11: MRF Waste Stream Capacity (tonnes)

Scenario	Waste Stream	2022 Baseline	2035 Capacity	2050 Capacity
1	C&I	19M	29M	45M
	C&D	22M	37M	66M
	LACW	10M	13M	17M
2	C&I	19M	28M	40M
	C&D	22M	33M	53M
	LACW	10M	12M	15M
3	C&I	19M	31M	48M
	C&D	22M	34M	56M
	LACW	10M	14M	21M
4	C&I	19M	29M	43M
	C&D	22M	33M	53M
	LACW	10M	12M	14M

2. With AD or EfW the waste feedstocks received will reach 'end of waste' status using a single process, that is the majority of the products and residues leaving those facilities are no longer considered a waste material needing further treatment. However most waste streams being sent to a MRF will require further process steps before 'end of waste' can be achieved. As a result, the MRF treatment tonnage is not necessarily a reflection of the actual waste arising as there may be several MRF steps needed to convert the waste stream back to a product. Some examples of this are:
    a. Many MRF's receiving DMR will produce a mixed plastic output product, or potentially several broad plastic types such as PET, HDPE and PP. These streams will need further treatment in a designated Plastic Recycling Facility (PRF) such as washing, contamination removal, flaking and pelletising before the product is in a suitable state for re-melt back into a new product. The PRF will receive the plastics from MRFs as a waste product, and so the same waste tonnage will effectively be treated twice.
    b. A food waste treatment MRF will receive packaged waste streams and will process them to separate the card or plastic packaging from the organic contents. The card and plastic may then be sent to a MRF for further sorting, whilst the organic content will be blended and sent to an AD facility for processing. As per the plastic scenario discussed above this will result in the waste stream effectively being processed twice.

As a result of this a clear distinction needs to be drawn between the waste arising and collected from households and businesses around the country, and the treatment capacity of facilities to process this material. The capacity is likely to exceed the waste arising for certain streams as many waste streams will be handled by multiple waste management facilities (which show up in the WDI data) before achieving end of waste status.

Landfill

Landfill capacity is estimated to reduce with diversion of materials away from landfill to other treatment routes. Under the modelling assumptions, some landfill capacity will be required in 2050 as it will not be possible to dispose of all waste types via alternative treatment/disposal methods. This stands at approximately 10Mt and 9Mt in scenarios 1 and 3 respectively, and 8Mt in scenarios 2 and 4. Materials such as hazardous waste will still need to be sent to landfill if unsuitable for combustion or other treatment. An example of this is the Air Pollution Control Residue from EfW facilities which is the by-product of the exhaust air clean-up process. This residue is classed as hazardous and as such landfill is currently the only available disposal route for it (although alternative recovery technologies are being explored).

EfW

Overall, EfW with or without CCS capacity is forecast to drop slightly as a result of waste reduction initiatives and the diversion of waste streams to other waste treatment routes. Additionally, unabated EfW capacity is estimated to reduce compared to the baseline down to approximately 1Mt in 2050 as a result of the transition to EfW with CCS.

AD

AD capacity is estimated to increase, with organic materials being diverted to this treatment method as a preference to composting. By 2050 in scenarios 1 and 3 the tonnage to AD is approximately 6Mt, with scenario 2 and 4 at 5Mt and 4Mt respectively. This is primarily driven by the target of near elimination of biodegradable municipal waste to landfill by 2030, and the introduction of separate food waste collections. This has considered organic materials being collected separately from the residual waste stream – this will be important to enable the output digestate product to meet PAS110 status[47] allowing it to be applied to land. If the input waste is not source segregated (i.e., is separated out from the residual waste post-collection) the digestate cannot be applied to land and is only suitable for land remediation and landfill capping under a bespoke environmental permit. This severely limits the useful application of the product, and in a worst-case scenario could result in the digestate being sent to EfW or landfill.

Composting/MBT

Composting and MBT capacity are estimated to remain relatively consistent over the project period. However, interest in MBT technologies is currently low as MBT relies on the organic fraction of the waste for the biological treatment to be effective. If waste management companies increasingly collect food waste separately from the rest of the residual waste there will be less organic matter in the waste stream, and the biological element of the MBT process will not function as effectively.

Furthermore, as discussed above in the AD summary, organic material which is derived from a mixed waste source is not allowed to be applied to land as a fertiliser, meaning the only disposal routes are land remediation or landfill capping. This means the organic output product is not attractive and will generally present a cost of disposal to operators.

However, there is an increasing interest in developing sustainable fuels using waste feedstocks as discussed below in the ATT section. These technologies often require comprehensive pre-treatment of the incoming waste streams to ensure they are of the right characteristics to be successfully converted. As a result, interest in MBT could increase again in the future as a means to produce low moisture content, higher calorific value waste derived fuels of consistent quality for conversion into fuels such as SAF.

Composting will remain as an attractive treatment route for green waste streams such as parks and gardens waste. Certain types of composting such as in-vessel composting (IVC) are also suitable for treatment of food waste containing animal by-products providing they meet strict residence time and temperature criteria.

ATT

ATT is unlikely to become a mainstream treatment route for MSW in the foreseeable future. The few ATT projects developed for the treatment of MSW derived RDF have not so far been commercially viable and so investment in the technology is limited. Where ATT may be more successful is in the treatment of certain waste streams such as plastic or biomass, or the treatment of relatively small quantities of waste to produce high value outputs. Some examples of this include:

[47] https://wrap.org.uk/resources/guide /bsi-pas-110-producing-quality-anaerobic-digestate

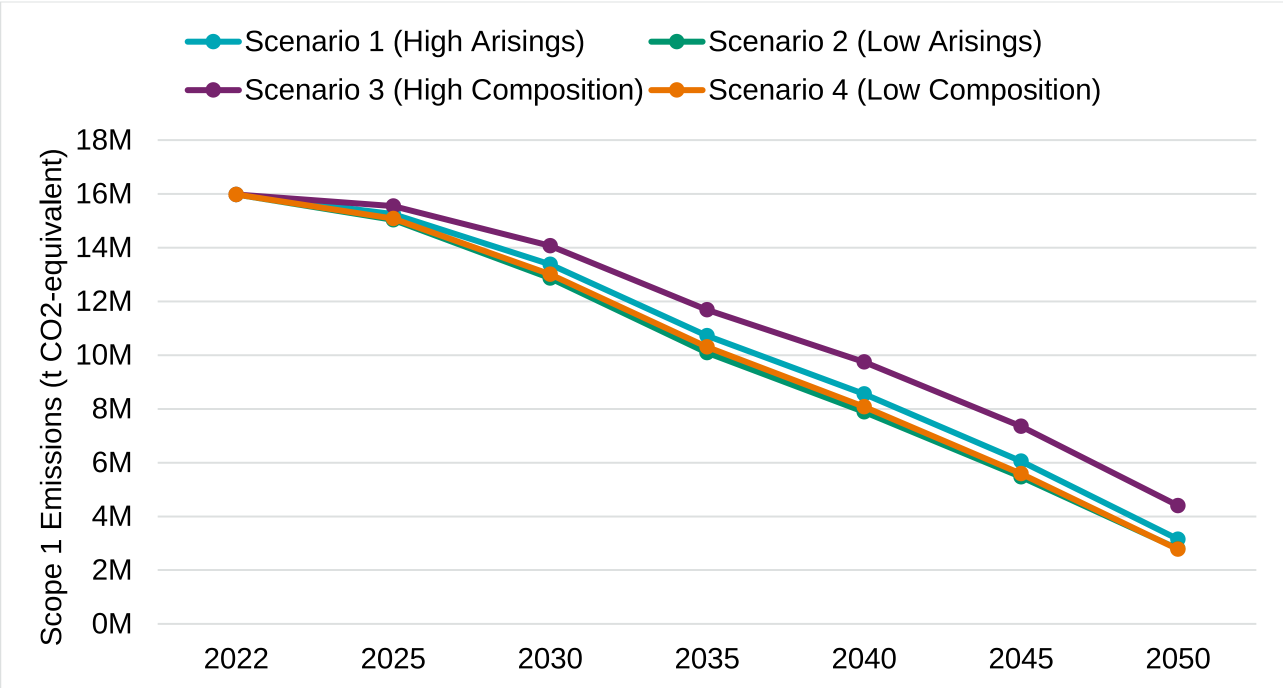
- Chemical recycling of plastics – using ATT to process hard to recycle plastics and turn them back into their constituent chemical parts, suitable for manufacturing new plastic.
- Waste to fuels – using ATT to process RDF into liquid fuels which can be a replacement for fossil fuels, such as sustainable aviation fuels (SAF).

There is currently a lot of interest in these technologies and chemical recycling is now being scaled up to become a more viable treatment route. Waste to fuels is still in the early development phase but may be starting to be more widely adopted over the next 20 – 30 years. It is unlikely to replace EfW with CCS as a long-term, large scale waste treatment solution within the short to medium term as the technology further develops on its way to become more proven.

3.2 GREENHOUSE GAS EMISSIONS

Figure 20 displays the results of the GHG emissions (t CO2e) modelled that will result from the waste tonnages forecasted from 2022 to 2055. Under the four modelled scenarios, each follow a similar trajectory to 2050 with the lowest emissions under scenarios 2 and 4 where there is lower waste arisings and lower waste composition as outlined within the modelling assumptions.

Figure 20: Comparison of GHG emissions by scenario



Key discussion points to achieve the lowest emissions possible by the year 2050:

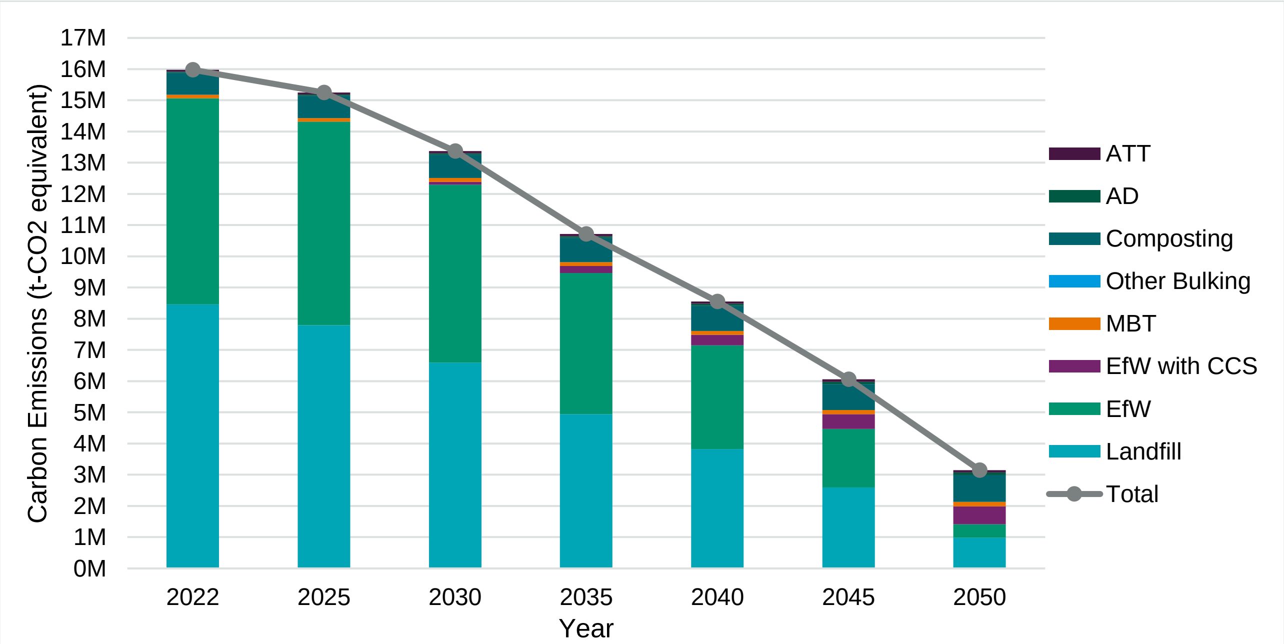
- All four scenarios achieve a reduction in scope 1 emissions of between 78% to 83% from 2022 to 2050. As there is little difference in the infrastructure mixture between the scenarios as the modelling assumptions are consistent, there is not a significant variation in GHG emissions across all four scenarios.
- Out of the four modelled scenarios, the lowest emissions in 2050 are approximately 2.8 MtCO2e under scenario 4 where the modelling assumptions include low arisings and low waste composition. Therefore, emissions are lower as for example there is less organic waste being treated at AD/composting facilities and consequently less emissions being generated.
- Whilst the modelling has looked to achieve the lowest possible emissions by 2050, positive emissions are still estimated due to the following factors:
  - Materials have largely been diverted from landfill, resulting in an overall reduction in emissions. But some materials are still likely to be required to be sent to landfill, resulting in some positive emissions from this disposal method in 2050.
  - EfW facilities have transitioned to EfW with CCS which has further helped to reduce CO2e emissions. CCS is expected to reduce emissions by 85%, so 15% of direct emissions will still

be present. Additionally, it is impracticable to assume that all EfW facilities will use CCS technology, so there is still expected to be some waste sent to EfW facilities (without CCS). Thus, there are expected to be net positive emissions from EfW facilities.

- The modelling undertaken only focuses on scope 1 emissions i.e., direct GHG emissions occurring from processes and equipment owned or controlled by the entity/facility.
  - Direct emissions include fugitive emissions from the decomposition of organic waste during composting and anaerobic digestion at landfills, as well as emissions from the combustion of waste.
  - The methodology has therefore not considered emissions from processes such as the mechanical sorting and processing of recyclables at dry recycling facilities, as the emissions associated arise from the purchase of electricity, and thus fall under scope 2[48].
  - Similarly, the methodology has not considered avoided emissions (or benefits) from recycling, as these fall under scopes 3 or 4.

The following Figure 21 to Figure 24 also show the GHG emissions broken down per facility type for each scenario.

Figure 21: Scenario 1 (High Arisings) Carbon emissions per facility type



[48] What are Scope 3 emissions and how it differs from Scope 1 and 2 | World Economic Forum (weforum.org)

Figure 22: Scenario 2 (Low Arisings) Carbon emissions per facility type

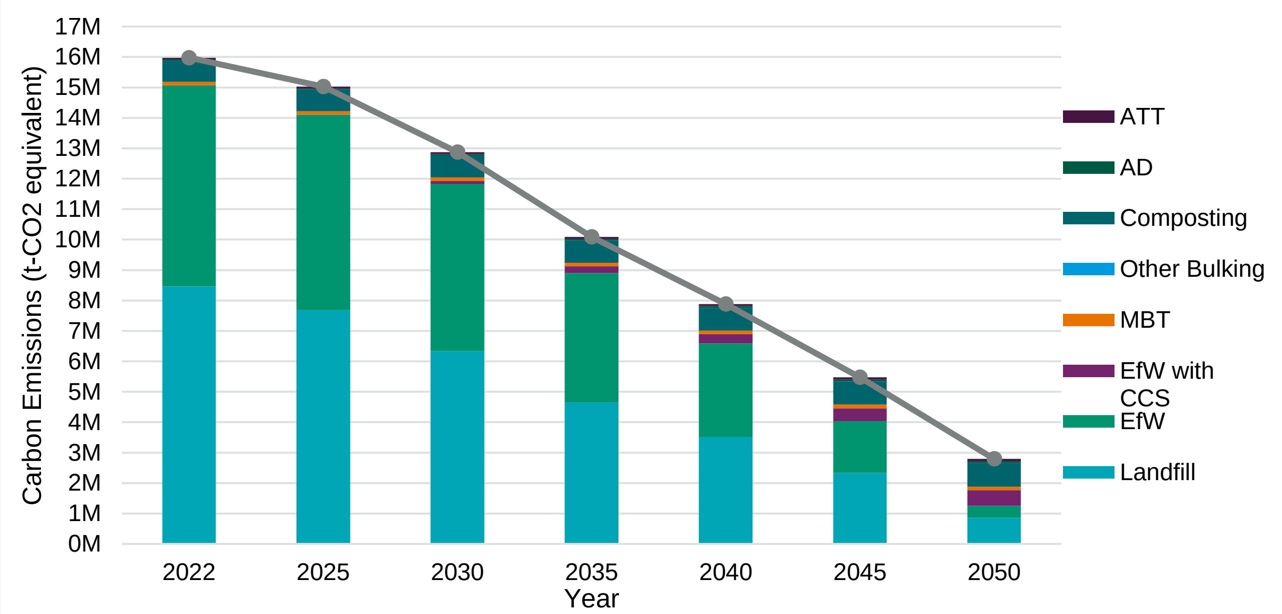


Figure 23: Scenario 3 (High Composition) Carbon emissions per facility type

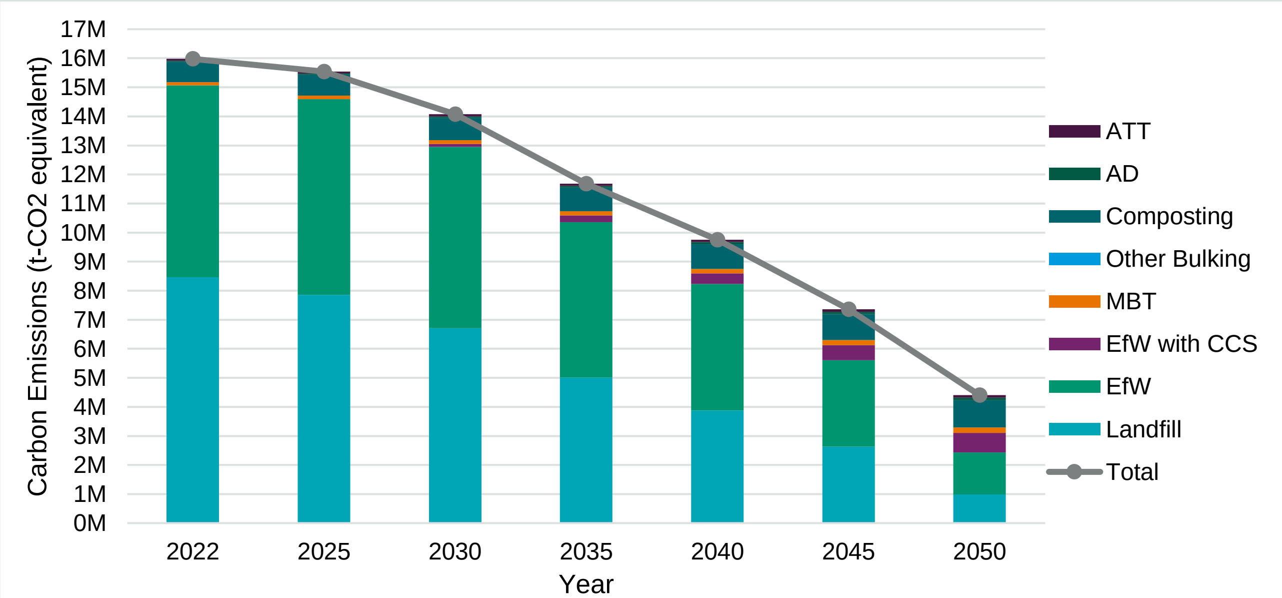
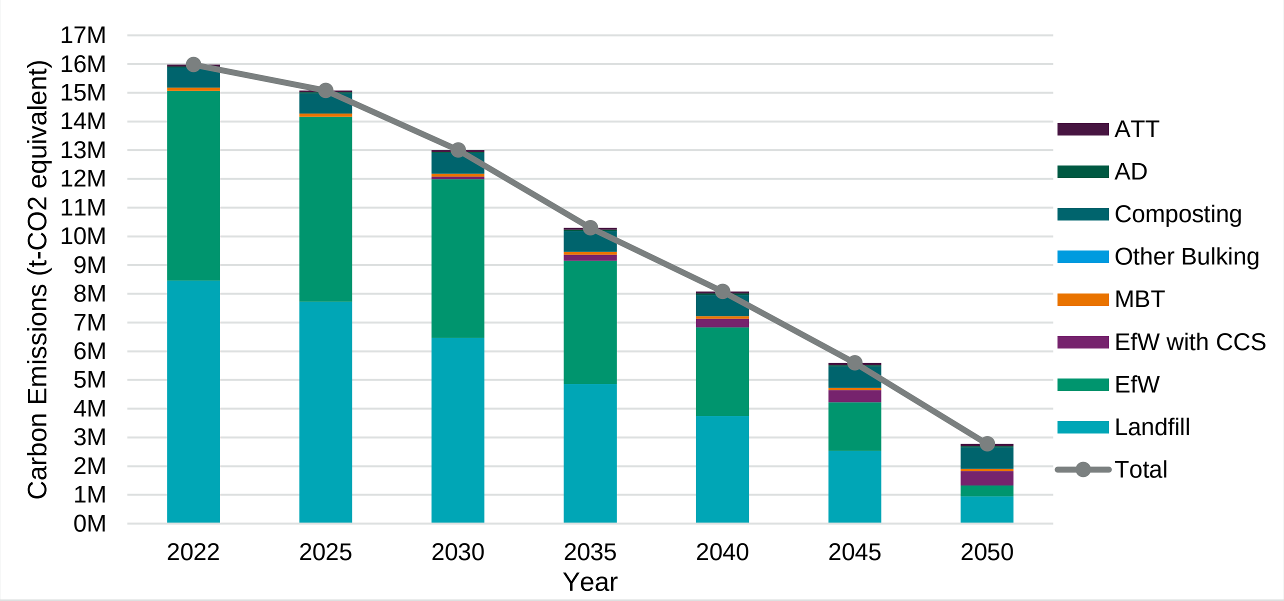


Figure 24: Scenario 4 (Low Composition) Carbon emissions per facility type



Key discussion points:

- As discussed above, the results provided show the lowest emissions pathway to 2050, broken down with the emissions contributed by each facility type under the different scenarios.
- The lowest emissions are achieved in scenario 4 where there are low arisings and low food, plastic, and paper and cardboard waste composition. With approximately 79% of waste being sent to MRF, 6% to both landfill and EfW with CCS respectively, 4% to Composting, 3% to AD, and 1% to both MBT and EfW without CCS.
- From the baseline year in 2022, emissions from landfill and EfW facilities have declined year on year as materials are being diverted to other treatment routes.
- Whilst EfW has transitioned to EfW with CCS, this will still contribute positive emissions of between approximately 0.5 MtCO2e to 0.7 MtCO2e across the scenarios in 2050.

3.3 COSTS

Figure 25 displays the results of the costs (capex + opex) modelled that are associated with the modelled waste tonnage and technology mix. The highest total cost in 2050 is associated with scenarios 1 and 3, with lower costs estimated for scenarios 2 and 4.

Figure 25: Comparison of cost (Capex + Opex) by scenario

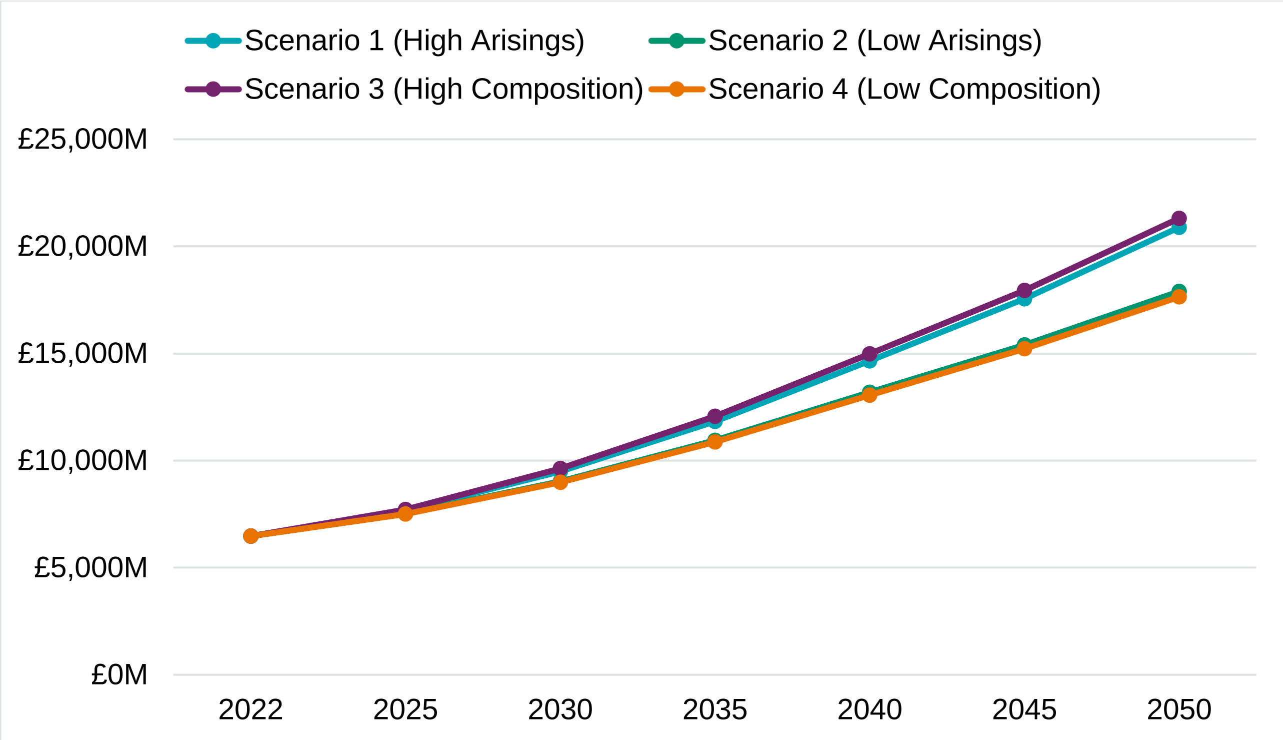


Figure 26 to Figure 29 show the costs broken down per facility type over the projected period.

Figure 26: Scenario 1 (High Arisings) Cost per facility type (Capex + Opex) [46]

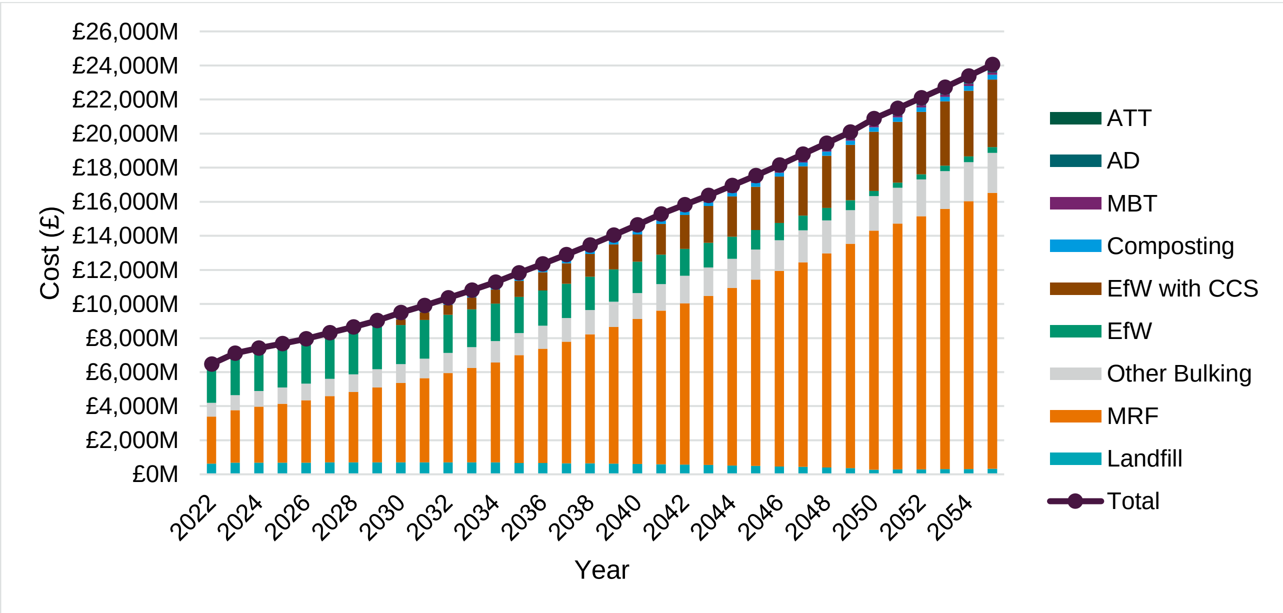


Figure 27: Scenario 2 (Low Arisings) Cost per facility type (Capex + Opex) [46]

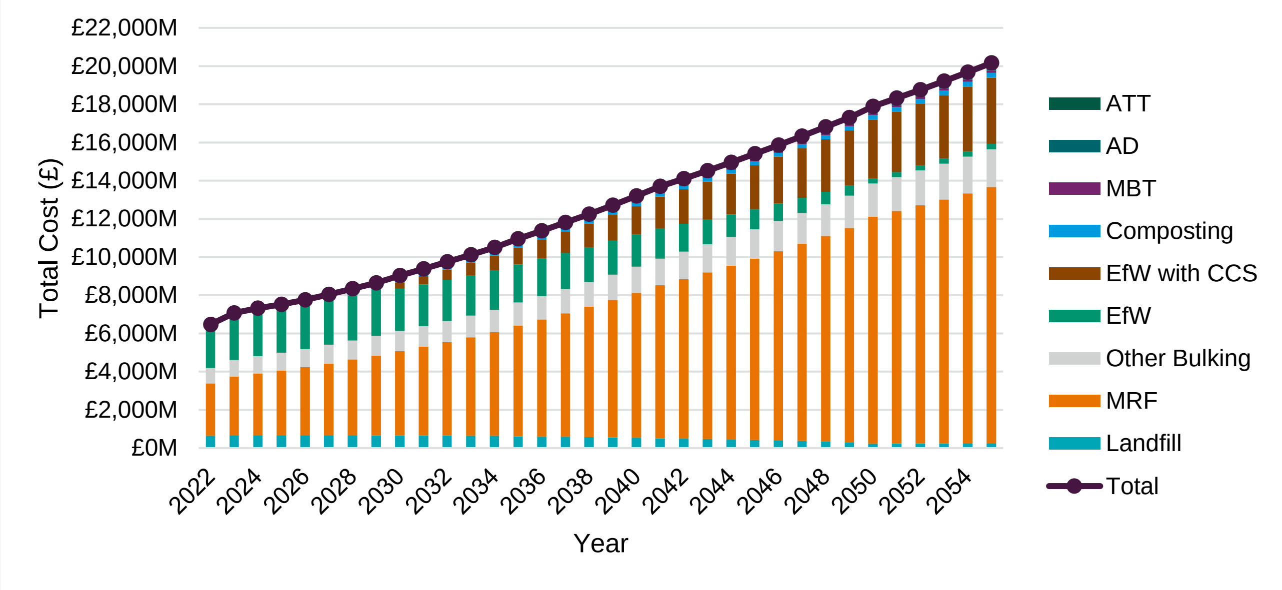


Figure 28: Scenario 3 (High Composition) Cost per facility type (Capex + Opex) [46]

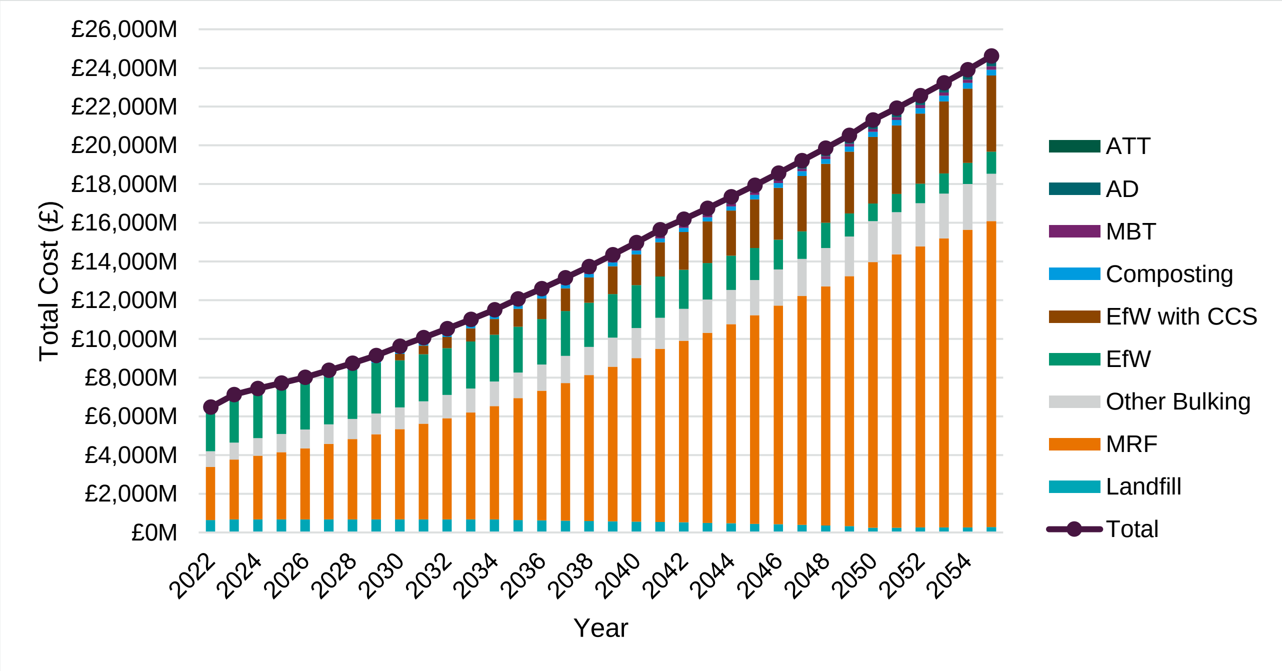
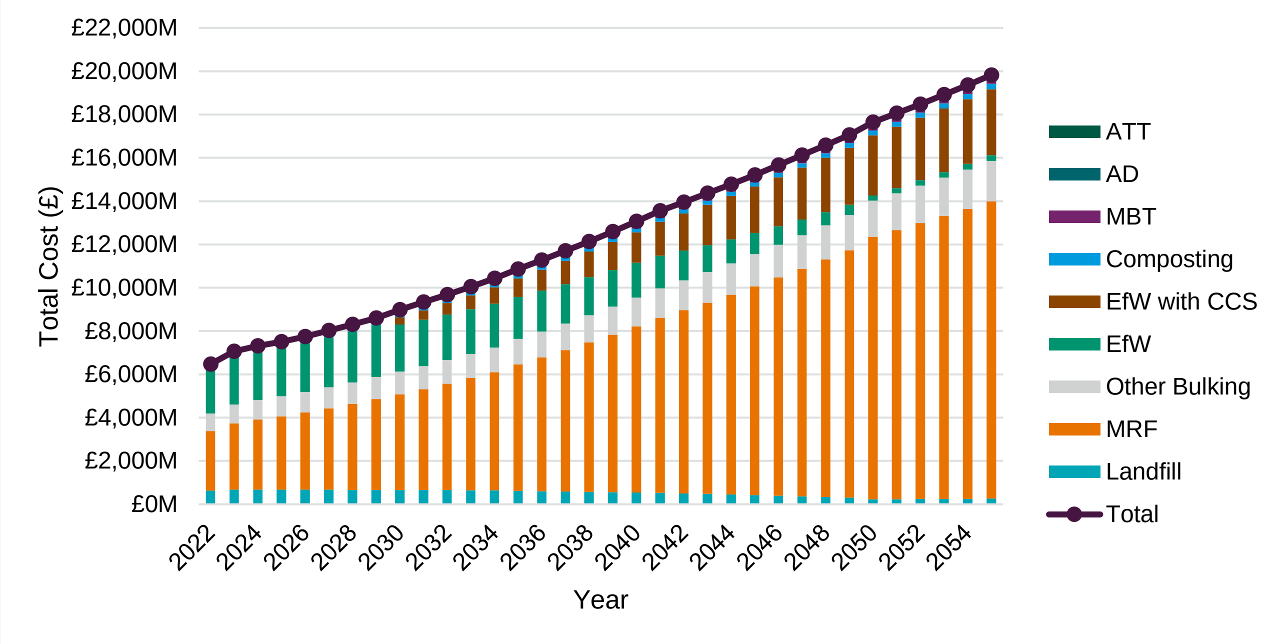


Figure 29: Scenario 4 (Low Composition) Cost per facility type (Capex + Opex) [46]



Key discussion points to achieve the lowest emissions possible by the year 2050:

- The highest total cost (Capex and Opex) in 2050 is associated with scenarios 1 and 3, with lower costs estimated for scenarios 2 and 4. This is due to the higher waste quantities attributed to scenarios 1 and 3 which require managing. Due to the optimal mix of technologies to lower emissions requiring most of the waste tonnage to be sent to MRF, the total costs for this treatment type are much higher than others by the end of the projected scenario timeline, accounting for approximately 67% of the total costs across all four scenarios.
- The costs in the modelling do not currently consider EfW in any future Emissions Trading Scheme (ETS), This was not included due to the variables and relative uncertainty about its implementation, however the government have recently confirmed EfW will be included from 2028. However, this modelling should be revised at the next infrastructure assessment once further details have been confirmed as it is likely to impact on the cost mechanisms for EfW facilities. The carbon price should ETS be Introduced is expected to be in the region of £45 - £90 per tonne CO_2 based on 2022 prices seen during the commencement of the UK ETS[49].

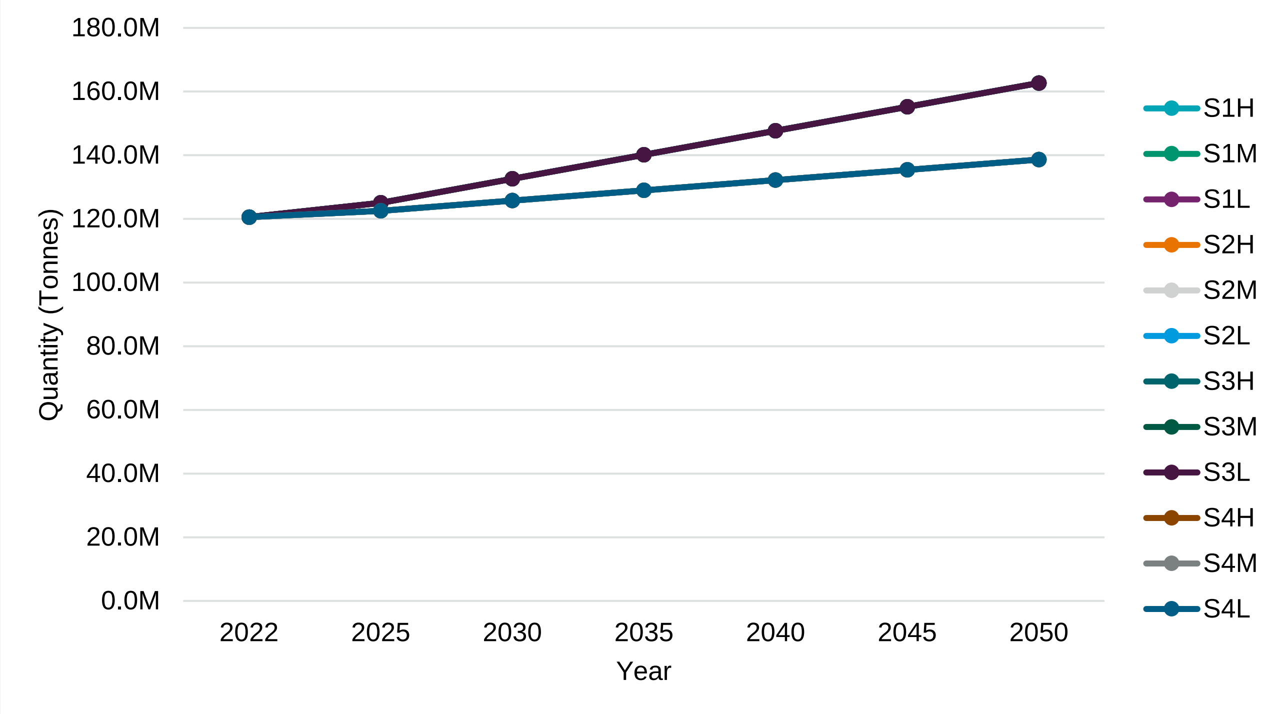
4. ENHANCED CIRCULARITY PATHWAY RESULTS

4.1 TECHNOLOGY MIX OF INFRASTRUCTURE & CAPACITY

In 2050 it is expected that the total tonnage of waste in England will rise in every scenario compared to the baseline year in 2022, shown in Figure 15. Therefore, even under the low scenario assumptions, in 2050 at the end of the projected period, an approximate additional 20Mt of waste will need managing in England. Figure 30Figure 15 shows all the ECP levels under scenarios 1 and 3 have the same tonnage arisings, as do the ECP levels under scenarios 2 and 4. Although the scenarios generate similar tonnages of waste the environmental impacts of the scenarios differ due to the difference in recycling and treatment of the waste streams which can be seen in Table 12.

[49] https://ember-climate.org/data/data-tools/carbon-price-viewer/

Figure 30: Comparison of total tonnes by scenario



The projected tonnage is identical for the different recycling levels in scenarios 1 and 3 and for scenarios 2 and 4. This is because scenarios 1 and 3 and their respective recycling levels have high waste arisings assumptions, with scenarios 2 and 4 following low waste arisings assumptions.

Table 12 displays the tonnages under each of the different scenarios and ECP level, broken down into the tonnes being sent to each infrastructure type in 2050. The values are presented in a graded colour scale on a row-by-row basis, with red being the highest respective values and green the lowest.

Table 12: Tonnage heat map for all scenarios in 2050. The total is excluding 'Other Bulking'.

2050	S1L	S1M	S1H	S2L	S2M	S2H	S3L	S3M	S3H	S4L	S4M	S4H
Landfill	9.99 M	9.99 M	9.99 M	8.21 M	8.21 M	8.21 M	8.77 M	8.77 M	8.77 M	8.39 M	8.39 M	8.39 M
EfW	1.12 M	1.01 M	0.90 M	0.97 M	0.88 M	0.81 M	1.66 M	1.48 M	1.32 M	0.94 M	0.88 M	0.80 M
EfW with CCS	9.85 M	8.90 M	7.87 M	8.77 M	7.93 M	7.32 M	11.14 M	9.54 M	8.08 M	8.16 M	7.65 M	6.89 M
MBT	1.51 M	1.34 M	1.05 M	1.34 M	1.19 M	0.94 M	1.89 M	1.89 M	1.89 M	1.13 M	1.13 M	1.13 M
MRF	127.75 M	128.58 M	129.33 M	108.28 M	108.97 M	109.34 M	125.49 M	126.69 M	127.83 M	110.29 M	110.68 M	111.38 M
Other Bulking	69.92 M	69.92 M	69.92 M	59.64 M	59.64 M	59.64 M	72.29 M	72.29 M	72.29 M	56.92 M	56.92 M	56.92 M
Composting	6.16 M	6.16 M	6.16 M	5.44 M	5.44 M	5.44 M	6.54 M	6.54 M	6.54 M	5.38 M	5.38 M	5.38 M
AD	6.10 M	6.49 M	7.18 M	5.43 M	5.84 M	6.39 M	6.97 M	7.55 M	8.03 M	4.17 M	4.35 M	4.49 M
ATT	0.19 M	0.19 M	0.19 M	0.17 M	0.17 M	0.17 M	0.20 M	0.20 M	0.20 M	0.18 M	0.18 M	0.18 M
Total	162.67 M	162.67 M	162.67 M	138.62 M	138.62 M	138.62 M	162.67 M	162.67 M	162.67 M	138.62 M	138.62 M	138.62 M

Material Recycling Facilities

The heat map shows that MRF capacity is likely to need to increase significantly, with tonnages sent to MRF increasing substantially across all scenarios and recycling rate options, to between 108Mt to 129Mt by 2050. This increased capacity will be required to enable a greater quantity of materials to be diverted from landfill or EfW and recycled instead. In each scenario the high recycling rate option shows the highest tonnage to MRF, as the priority waste types are diverted in order for the circularity rates to be achieved.

The drivers for the increase in capacity requirements are the policy commitments, outlined in the modelling assumptions. These will result in the increased capture of more recyclable materials and the diversion of waste from disposal, pushing it further up the waste hierarchy, ultimately increasing the demand for MRF capacity. A key aspect of this will be the successful separation and recycling of recyclable materials from mixed waste streams. This will likely involve a mix of:

- Increased capture of recyclables (e.g., encouraging participation by ensuring the appropriate infrastructure is in-place, communication and education campaigns).
- Improved processing to capture recyclables that are mixed into mixed and residual waste streams (e.g., automated technology separating recyclable materials that are disposed of in the residual waste bin).

Landfill

Landfill capacity is estimated to reduce to between 8M-10Mt across all scenarios and recycling rates. This is a result of the diversion of materials to other treatment routes. Under the modelling assumptions, some landfill capacity will be required in 2050 as not all waste types will be able to be disposed of via alternative treatment/disposal methods. Materials such as hazardous waste will still need to be sent to landfill if unsuitable for combustion or other treatment. An example of this is the Air Pollution Control Residue from EfW facilities which is the by-product of the exhaust air clean-up process. This residue is classed as hazardous and as such landfill is currently the only available disposal route for it (although alternative recovery technologies are being explored).

EfW

EfW capacity is estimated to reduce compared to the baseline to between 0.8Mt to 2Mt by 2050 with a transition to EfW with CCS, increasing to between 7Mt to 11Mt by 2050. The government is incentivising the development of EfW with CCS technologies to help de-carbonise the sector. Across the scenarios the low recycling rate options have an increased amount of tonnage to EfW and EfW with CCS as a result of less material being sent to MRF and AD.

AD

AD capacity is estimated to increase to between 4Mt to 8Mt by 2050 across all scenarios and recycling rates. This is a result of organic materials being diverted to this treatment method in preference to composting along with the target of near elimination of biodegradable municipal waste to landfill by 2030, and the introduction of separate food waste collections.

Composting/MBT

Composting and MBT capacity are estimated to remain relatively consistent across the scenarios and recycling options, with MBT tonnages higher in the low recycling options. However, interest in MBT technologies is currently low as MBT relies on the organic fraction of the waste for the biological treatment to be effective. If waste management companies increasingly collect food waste separately from the rest of the residual waste there will be less organic matter in the waste stream, and the biological element of the MBT process will not function as effectively.

Composting will remain as an attractive treatment route for green waste streams such as parks and gardens waste. Certain types of composting such as in-vessel composting (IVC) are also suitable for treatment of food waste containing animal by-products providing they meet strict residence time and temperature criteria.

ATT

ATT is unlikely to become a mainstream treatment route for MSW in the foreseeable future. The few ATT projects developed for the treatment of MSW derived RDF have not so far been commercially viable and so investment in the technology is limited. Where ATT may be more successful is in the treatment of certain waste streams such as plastic or biomass, or the treatment of relatively small quantities of waste to produce high value outputs. Some examples of this include:

- Chemical recycling of plastics – using ATT to process hard to recycle plastics and turn them back into their constituent chemical parts, suitable for manufacturing new plastic.
- Waste to fuels – using ATT to process RDF into liquid fuels which can be a replacement for fossil fuels, such as sustainable aviation fuels (SAF).

There is currently a lot of interest in these technologies and chemical recycling is now being scaled up to become a more viable treatment route. Waste to fuels is still in the early development phase but may be starting to be more widely adopted over the next 20 – 30 years.

More detailed tonnage results over the projected timeline for each of the individual scenario and recycling level are presented in Figure 39 to Figure 50 within the Appendix.

These results show;

- Baseline waste tonnages for all scenarios are approximately 120Mt, in 2022.
- Projections increase to approximately 160Mt by 2050 (excluding ‘Other bulking’) for Scenario 1 and 3.
- Projections increase to approximately 140Mt by 2050 (excluding ‘Other bulking’) for Scenario 2 and 4.

It can be seen from the figures that the projected amount of waste being landfilled, sent to EfW, and to EfW with CCS from 2022 to 2050 will reduce year on year as dry recyclables will be diverted to MRFs. EfW tonnages decrease to between 0.8Mt to 2Mt by 2050 as materials transitions to EfW with CCS, which increases to between 7Mt to 11Mt by 2050.

MRF capacity increases from approximately 51Mt in 2022 to more than 127Mt, 108Mt, 128Mt and 109Mt in 2050 for the four Scenarios respectively depending on the low, medium and high option. The specific Scenario and Option figures can be seen in Table 6.

Table 13: Facility distribution heat map for all scenarios in 2050. Excluding 'Other Bulking'.

2050	S1L	S1M	S1H	S2L	S2M	S2H	S3L	S3M	S3H	S4L	S4M	S4H
Landfill	6.1%	6.1%	6.1%	5.9%	5.9%	5.9%	5.4%	5.4%	5.4%	6.0%	6.0%	6.0%
EfW	0.7%	0.6%	0.6%	0.7%	0.6%	0.6%	1.0%	0.9%	0.8%	0.7%	0.6%	0.6%
EfW with CCS	6.1%	5.5%	4.8%	6.3%	5.7%	5.3%	6.8%	5.9%	5.0%	5.9%	5.5%	5.0%
MBT	0.9%	0.8%	0.6%	1.0%	0.9%	0.7%	1.2%	1.2%	1.2%	0.8%	0.8%	0.8%
MRF	78.5%	79.0%	79.5%	78.1%	78.6%	78.9%	77.1%	77.9%	78.6%	79.6%	79.8%	80.3%
Other Bulking	43.0%	43.0%	43.0%	43.0%	43.0%	43.0%	44.4%	44.4%	44.4%	41.1%	41.1%	41.1%
Composting	3.8%	3.8%	3.8%	3.9%	3.9%	3.9%	4.0%	4.0%	4.0%	3.9%	3.9%	3.9%
AD	3.8%	4.0%	4.4%	3.9%	4.2%	4.6%	4.3%	4.6%	4.9%	3.0%	3.1%	3.2%
ATT	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%
Total	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

The proportion of materials treated at the individual facility for the Options and Scenarios in 2050 can be seen in Table 13. This maps the tonnage results presented in Table 12.

4.2 COSTS

Figure 31 display the results of the costs (Capex + Opex) modelled that are associated with the modelled waste arisings and technology mix. The highest total cost in 2050 is associated with the low recycling rate option for scenarios 3 and 1. For a more detailed breakdown, Figure 51 – Figure 62 in the appendix show the costs per facility type for each of the scenarios and recycling rate options.

Figure 31: Comparison of cost (Capex + Opex) by scenario

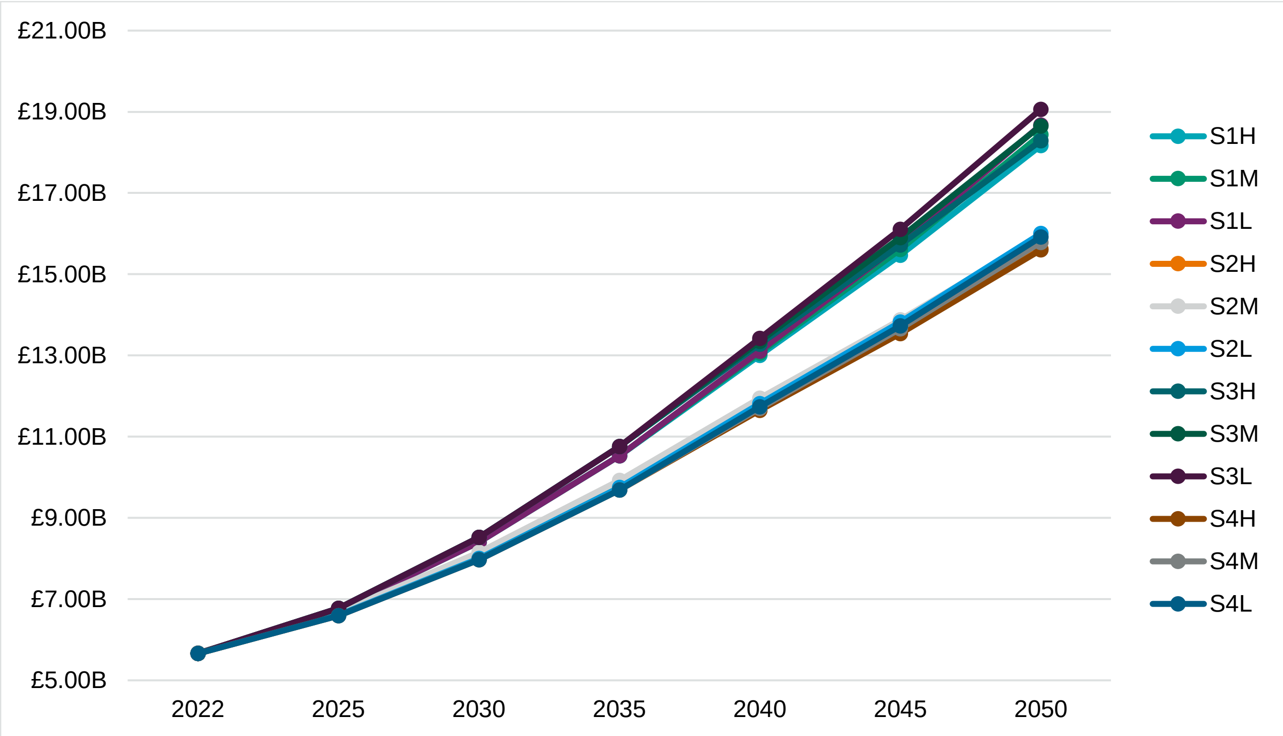


Table 14: Total cost waste heat map for all scenarios in 2050 - 'Other Bulking' is excluded from total.

2050	S1L	S1M	S1H	S2L	S2M	S2H	S3L	S3M	S3H	S4L	S4M	S4H
Landfill	£273 M	£273 M	£273 M	£224 M	£224 M	£224 M	£239 M	£239 M	£239 M	£229 M	£229 M	£229 M
EfW	£284 M	£257 M	£228 M	£247 M	£237 M	£206 M	£421 M	£376 M	£335 M	£238 M	£223 M	£202 M
EfW with CCS	£3,259 M	£2,946 M	£2,603 M	£2,903 M	£2,753 M	£2,423 M	£3,684 M	£3,156 M	£2,673 M	£2,699 M	£2,529 M	£2,278 M
MBT	£119 M	£106 M	£83 M	£106 M	£99 M	£74 M	£150 M	£150 M	£150 M	£89 M	£89 M	£89 M
MRF	£14,060 M	£14,153 M	£14,235 M	£11,918 M	£11,993 M	£12,035 M	£13,812 M	£13,944 M	£14,070 M	£12,139 M	£12,182 M	£12,259 M
Other Bulking	£2,039 M	£2,039 M	£2,039 M	£1,739 M	£1,739 M	£1,739 M	£2108 M	£2,108 M	£2,108 M	£1,660 M	£1,660 M	£1,660 M
Composting	£251 M	£251 M	£251 M	£221 M	£221 M	£221 M	£266 M	£266 M	£266 M	£219 M	£219 M	£219 M
AD	£390 M	£415 M	£459 M	£347 M	£373 M	£408 M	£445 M	£482 M	£513 M	£266 M	£278 M	£287 M
ATT	£38 M	£38 M	£38 M	£34 M	£34 M	£34 M	£41 M	£41 M	£41 M	£36 M	£36 M	£36 M
Total	£18,673 M	£18,437 M	£18,168 M	£16,000 M	£15,935 M	£15,625 M	£19,059 M	£18,654 M	£18,287 M	£15,914 M	£15,785 M	£15,598 M

Table 15 Cost per tonne waste heat map for all scenarios in 2050.

2050	S1L	S1M	S1H	S2L	S2M	S2H	S3L	S3M	S3H	S4L	S4M	S4H
Landfill	£27	£27	£27	£27	£27	£27	£27	£27	£27	£27	£27	£27
EfW	£253	£253	£253	£253	£269	£253	£253	£253	£253	£253	£253	£253
EfW with CCS	£331	£331	£331	£331	£347	£331	£331	£331	£331	£331	£331	£331
MBT	£79	£79	£79	£79	£83	£79	£79	£79	£79	£79	£79	£79
MRF	£110	£110	£110	£110	£110	£110	£110	£110	£110	£110	£110	£110
Other Bulking	£29	£29	£29	£29	£29	£29	£29	£29	£29	£29	£29	£29
Composting	£41	£41	£41	£41	£41	£41	£41	£41	£41	£41	£41	£41
AD	£64	£64	£64	£64	£64	£64	£64	£64	£64	£64	£64	£64
ATT	£203	£203	£203	£203	£203	£203	£203	£203	£203	£203	£203	£203
Total	£115	£113	£112	£115	£115	£113	£117	£115	£112	£115	£114	£113

Cost results over the projected timeline for each of the individual scenario and recycling level are presented in Figure 51 to Figure 62 within the Appendix.

Overall, these results show the total cost of treatment of waste for each facility for all scenarios and recycling rate options through the projected period until 2050. The baseline cost is approximately £5.7B in 2022 and is estimated to increase to between £15.6B-£18.7B by 2050 depending on the scenarios and options. The specific Scenario and Option figures can be seen in Table 14 and Table 15.

Due to the optimal mix of technologies to lower emissions requiring most of the waste to be sent to MRF, the overall costs for this treatment type are much higher than others by the end of the projected scenario timeline, although the actual cost per tonne is lower than EfW and EfW with CCS. Across the options the overall cost of MRF increases with the recycling rate, as more waste is required to be sent to meet the circularity targets.

In all scenarios, the results for the high recycling rate option are the lowest cost per scenario (on a per tonne basis). This is a result of the diversion of the priority materials away from EfW and EfW with CCS to MRF and AD.

4.3 ENVIRONMENTAL IMPACTS

The environmental impacts modelled as a result of the 12 ECP scenarios were:

1. Carbon emissions
2. Acidification potential
3. Eutrophication potential
4. Freshwater aquatic ecotoxicology potential
5. Human toxicity potential
6. Depletion of abiotic resources potential

4.3.1 Carbon Emissions

Figure 32 displays the results of the GHG emissions (t CO2e) modelled from the waste arisings from 2022 to 2050. In 2022 the total amount of CO2e emissions was just under 16 Mt CO2e. Diverting waste up the waste management hierarchy, from landfill and EfW to recycling, results in a reduction in the total amounts of CO2e emissions by 2050 to be in the range of 2.5 – 3.1 Mt CO2e.

Figure 32: Comparison of carbon emissions per scenario

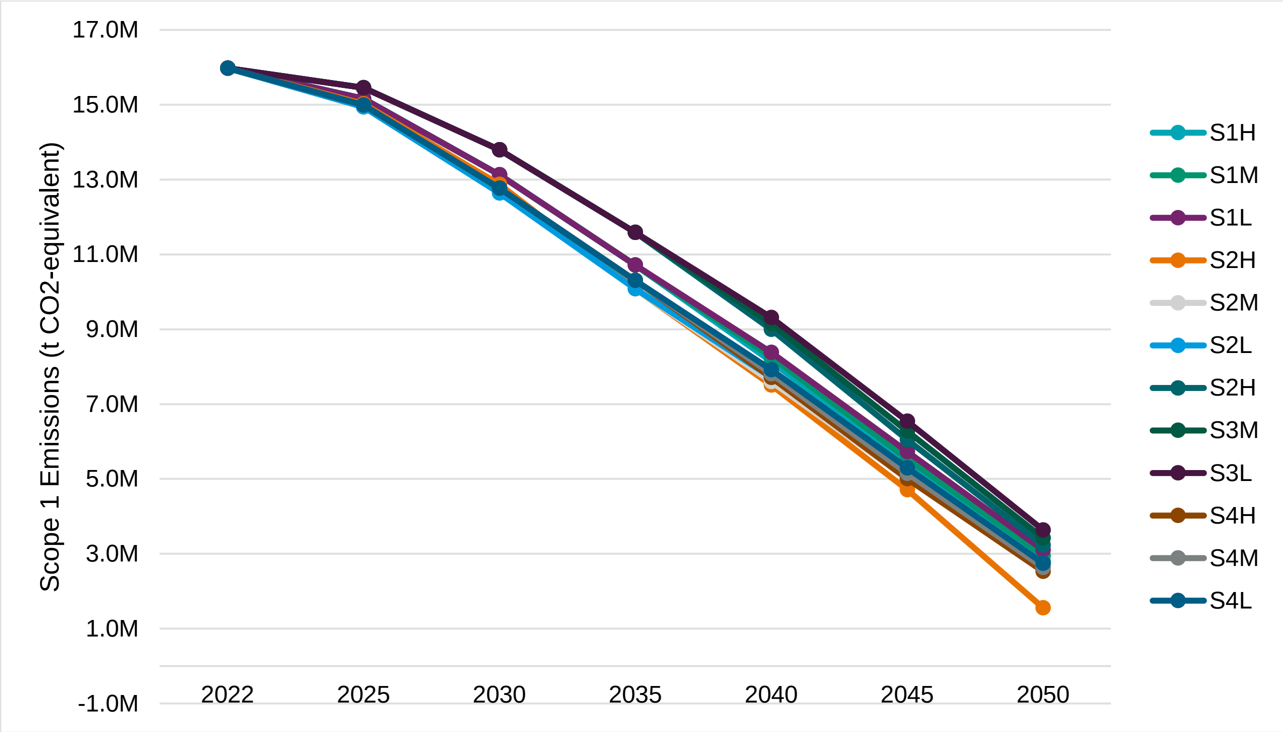


Table 16: Heat map of the Global warming potential (tonnes C02e) for the treated waste for all scenarios in 2050 - Total is excluding 'Other Bulking' and not accounting for offsetting the raw material production of the recyclable materials.

2050	S1L	S1M	S1H	S2L	S2M	S2H	S3L	S3M	S3H	S4L	S4M	S4H
Landfill	985,234	985,234	985,234	865,362	865,362	865,362	991,744	991,744	991,744	948,718	948,718	948,718
EfW	406,815	349,890	298,486	357,396	306,708	286,720	631,536	535,279	449,910	368,582	319,759	274,120
EfW with CCS	541,344	464,494	395,099	482,484	414,056	387,073	706,853	576,906	461,658	484,347	418,436	356,823
MBT	137,601	115,774	70,941	122,521	103,086	63,167	183,067	183,067	183,067	73,387	73,387	73,387
MRF	0	0	0	0	0	0	0	0	0	0	0	0
Other Bulking	0	0	0	0	0	0	0	0	0	0	0	0
Composting	868,361	868,361	868,361	772,513	772,513	772,513	939,607	939,607	939,607	751,238	751,238	751,238
AD	85,564	93,287	107,105	76,187	84,431	95,367	101,894	113,431	123,046	47,575	51,096	54,031
ATT	77,311	77,311	77,311	68,838	68,838	68,838	83,361	83,361	83,361	72,789	72,789	72,789
Total	3,102,229	2,954,350	2,802,537	2,745,301	2,614,995	2,539,040	3,638,062	3,423,395	3,232,392	2,746,635	2,635,424	2,531,106

Table 16 shows the carbon emissions for each scenario and recycling rate option in 2050.

In 2022 landfill accounts for almost 8.5Mt of CO2e which is reduced to approximately 1Mt CO2e by 2050. EfW, both with and without CCS, sees a similar reduction going from 6.5Mt CO2e to 0.5-1Mt CO2e depending on the scenario and options. This is because diverting recyclables from landfill and EfW to MRF and diverting food waste to AD treatment facilities brings about a noticeable reduction in CO2e emissions.

The low arisings options have the lowest emissions for the individual scenarios, with Scenario 2 and 4 showing the overall lowest emissions. These scenarios are not bringing the waste management to net zero as there are still emissions being emitted for the landfill disposal and through the EfW and ATT facilities.

Although there are emissions associated with the treatment of organic wastes in composting and AD facilities, those facilities are offsetting these emissions through the displacement of fuels and virgin materials in the economy. This offsetting of the raw material production through recycling is not reflected in Table 166. The composting facilities are generating fertilisers retaining nitrate, potassium and phosphorous from the composted material. The AD facilities are generating methane gasses which is captured and used for energy production and offsetting the use of natural gas.

4.3.2 Acidification

Figure 33: Comparison of acidification potential per scenario

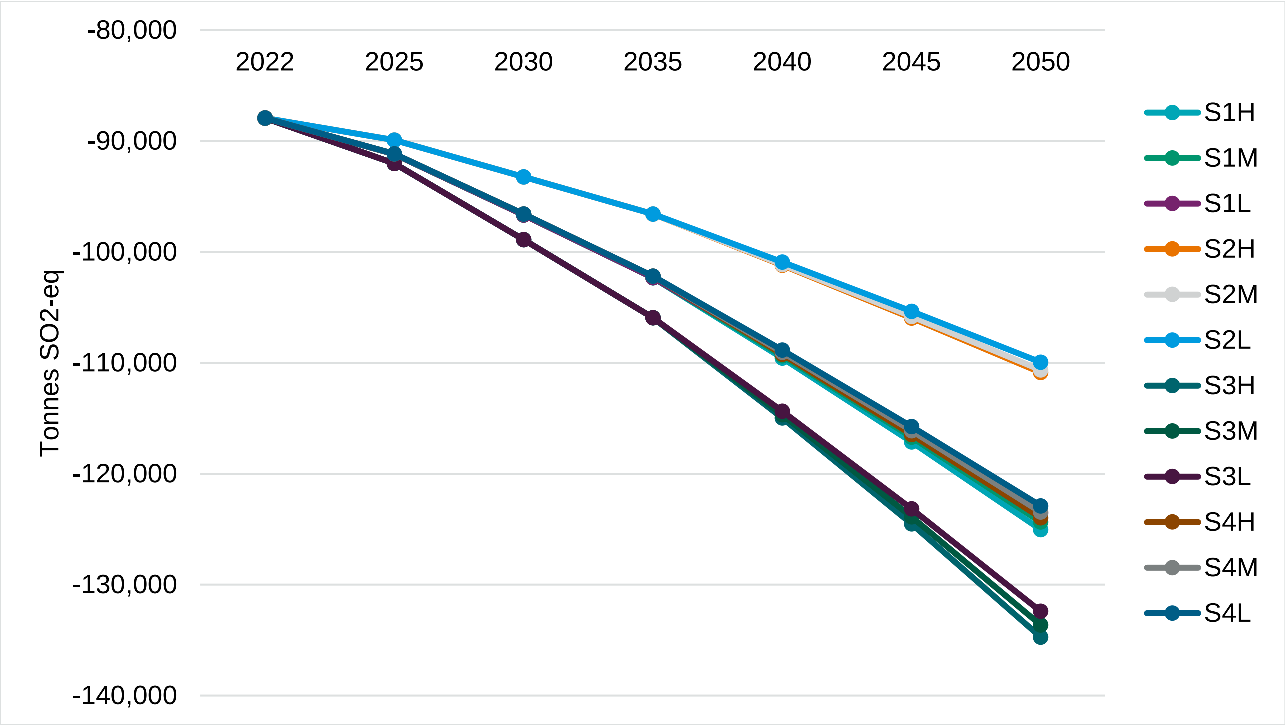


Table 17: Heat map of the acidification emissions (tonnes SO2-eq) associated with the waste treatment for all scenarios in 2050 - Total is excluding 'Other Bulking'.

2050	S1L	S1M	S1H	S2L	S2M	S2H	S3L	S3M	S3H	S4L	S4M	S4H
Landfill	848	848	848	697	697	697	745	745	745	712	712	712
EfW	380	359	328	330	308	284	548	514	484	318	304	291
EfW with CCS	3,816	3,594	3,269	3,399	3,168	2,916	4,018	3,655	3,342	3,152	3,000	2,860
MBT	-654	-648	-654	-583	-577	-582	-706	-706	-706	-672	-672	-672
MRF	-132,324	-133,106	-133,825	-117,676	-118,372	-118,635	-141,961	-143,133	-144,159	-129,525	-130,030	-130,472
Other Bulking	942	942	942	801	801	801	964	964	964	768	768	768
Composting	2,576	2,576	2,576	2,294	2,294	2,294	2,702	2,702	2,702	2,444	2,444	2,444
AD	1,793	2,020	2,426	1,596	1,839	2,160	2,245	2,585	2,867	685	789	875
ATT	5	5	5	4	4	4	5	5	5	4	4	4
Total	-123,559	-124,351	-125,026	-109,937	-110,639	-110,861	-132,403	-133,634	-134,719	-122,882	-123,449	-123,958

Figure 33 shows that all the waste treatment infrastructure types have a saving of around 90 k tonnes of SO_{2-eq} in 2022 and the offset in emissions continues to 2050 resulting in around 110 k tonnes to 125 k tonnes saved SO_{2-eq} emissions by 2050, as seen in Table 17. The savings originate from the recyclables managed in the MRF as it offsets virgin production of commodities. The best performing scenarios are 1 and 4 for the acidification, with scenario 1 performing around 2,000 tonnes better in 2050.

4.3.3 Eutrophication

Figure 34: Comparison of eutrophication potential per scenario

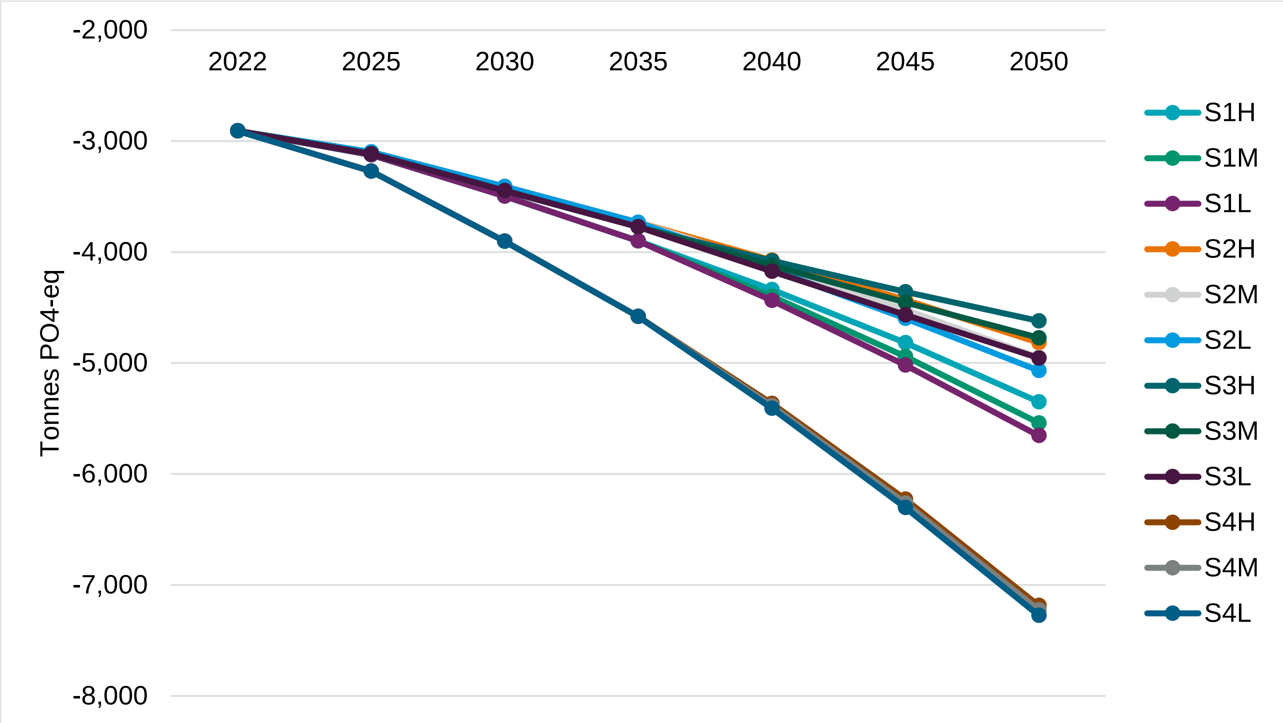


Table 18: Heat map of the eutrophication emissions (tonnes PO4-eq), associated with the waste treatment for all scenarios in 2050 -Total is excluding 'Other Bulking'.

2050	S1L	S1M	S1H	S2L	S2M	S2H	S3L	S3M	S3H	S4L	S4M	S4H
Landfill	419	419	419	344	344	344	367	367	367	351	351	351
EfW	112	105	95	98	90	83	162	151	141	94	89	84
EfW with CCS	1,081	1,011	915	963	892	820	1,156	1,042	943	895	846	800
MBT	55	40	16	49	36	14	76	76	76	20	20	20
MRF	-9,964	-9,908	-9,857	-8,874	-8,824	-8,806	-9,743	-9,660	-9,586	-10,432	-10,396	-10,364
Other Bulking	158	158	158	134	134	134	162	162	162	129	129	129
Composting	1,454	1,454	1,454	1,295	1,295	1,295	1,538	1,538	1,538	1,344	1,344	1,344
AD	1,189	1,340	1,609	1,059	1,220	1,433	1,489	1,714	1,902	455	523	581
ATT	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
Total	-5,655	-5,540	-5,350	-5,068	-4,949	-4,817	-4,955	-4,772	-4,621	-7,274	-7,224	-7,186

Figure 34 shows that all the waste treatment infrastructure types have a saving of around 3,000 tonnes of PO_{4-eq} in 2022 and the offset in emissions continues to 2050 resulting in around 3,800 tonnes to 7,300 tonnes saved PO_{4-eq} emissions by 2050, as seen in Table 18. The savings originate from the recyclables managed in the MRF as it offsets virgin production of commodities. For eutrophication, scenario 4 shows the biggest potential savings in emissions.

4.3.4 Freshwater Aquatic Ecotoxicology

Figure 35: Comparison of freshwater aquatic ecotoxicology potential per scenario

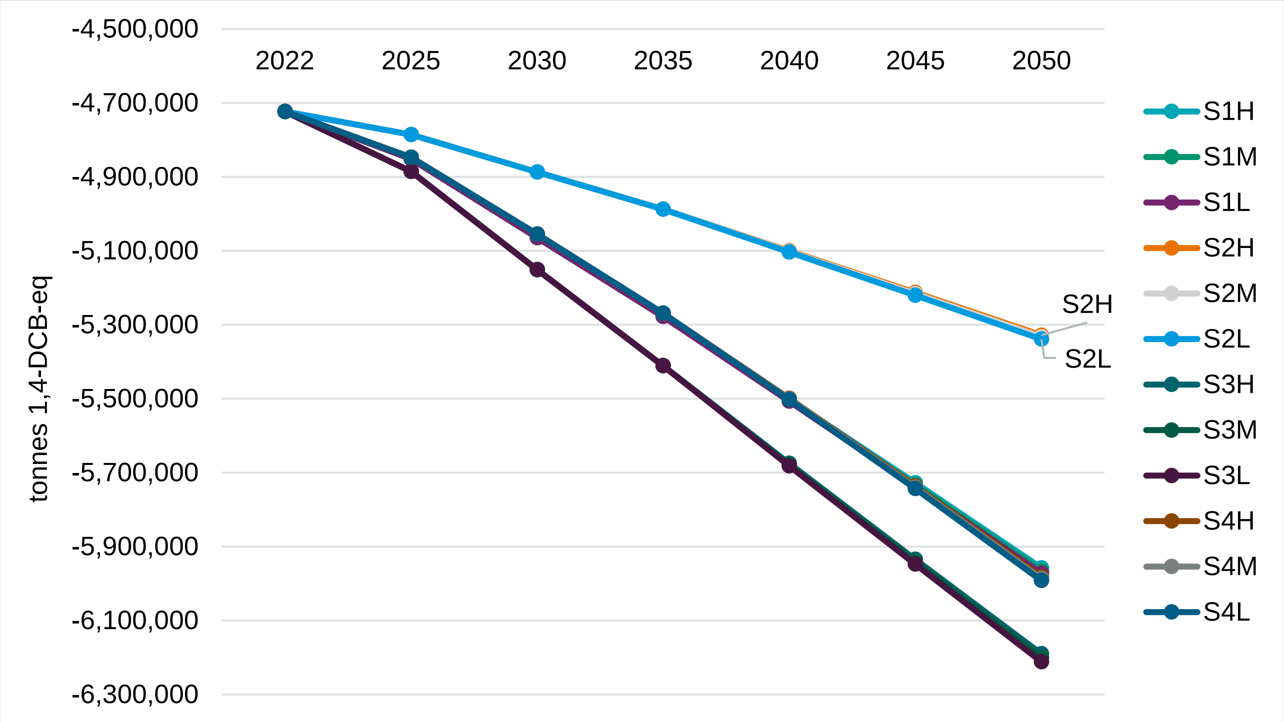


Table 19: Heat map of the freshwater aquatic ecotoxicology emissions (tonnes 1,4-DCB-eq) associated with the waste treatment for all scenarios in 2050 - Total is excluding 'Other Bulking'.

2050	S1L	S1M	S1H	S2L	S2M	S2H	S3L	S3M	S3H	S4L	S4M	S4H
Landfill	21,514	21,514	21,514	17,735	17,735	17,735	18,999	18,999	18,999	18,175	18,175	18,175
EfW	-2,142	-1,744	-1,436	-1,879	-1,540	-1,457	-3,441	-2,782	-2,194	-2,056	-1,692	-1,345
EfW with CCS	-2,039	461	1,787	-1,801	165	-126	-8,715	-4,563	-810	-4,175	-1,685	707
MBT	-63,231	-63,580	-63,954	-56,302	-56,613	-56,946	-64,682	-64,682	-64,682	-62,891	-62,891	-62,891
MRF	-5,955,092	-5,953,825	-5,952,662	-5,321,995	-5,320,867	-5,320,441	-6,189,230	-6,187,332	-6,185,672	-5,951,731	-5,950,913	-5,950,197
Other Bulking	30,366	30,366	30,366	25,831	25,831	25,831	31,065	31,065	31,065	24,755	24,755	24,755
Composting	4,619	4,619	4,619	4,113	4,113	4,113	5,496	5,496	5,496	2,572	2,572	2,572
AD	25,306	28,511	34,245	22,532	25,954	30,492	31,695	36,483	40,473	9,675	11,136	12,354
ATT	-1,423	-1,423	-1,423	-1,267	-1,267	-1,267	-1,526	-1,526	-1,526	-1,392	-1,392	-1,392
Total	-5,972,486	-5,965,466	-5,957,309	-5,338,863	-5,332,319	-5,327,897	-6,211,404	-6,199,907	-6,189,916	-5,991,823	-5,986,690	-5,982,018

Figure 35 shows that all the waste treatment infrastructure types have a saving of around 4.7Mt of 1,4-DCB$_e$ in 2022 and the offset in emissions continues to 2050 resulting in around 5.3Mt to 6.0Mt saved 1,4-DCB$_e$ emissions by 2050, as seen in Table 19. The savings originate from the recyclables managed in the MRF as it offsets virgin production of commodities. The emissions associated with freshwater aquatic ecotoxicology are found in the landfill, other bulking and AD treatment. The biggest saving can be found in either Scenario 1 or 4.

4.3.5 Human Toxicity

Figure 36: Comparison of human toxicity potential per scenario

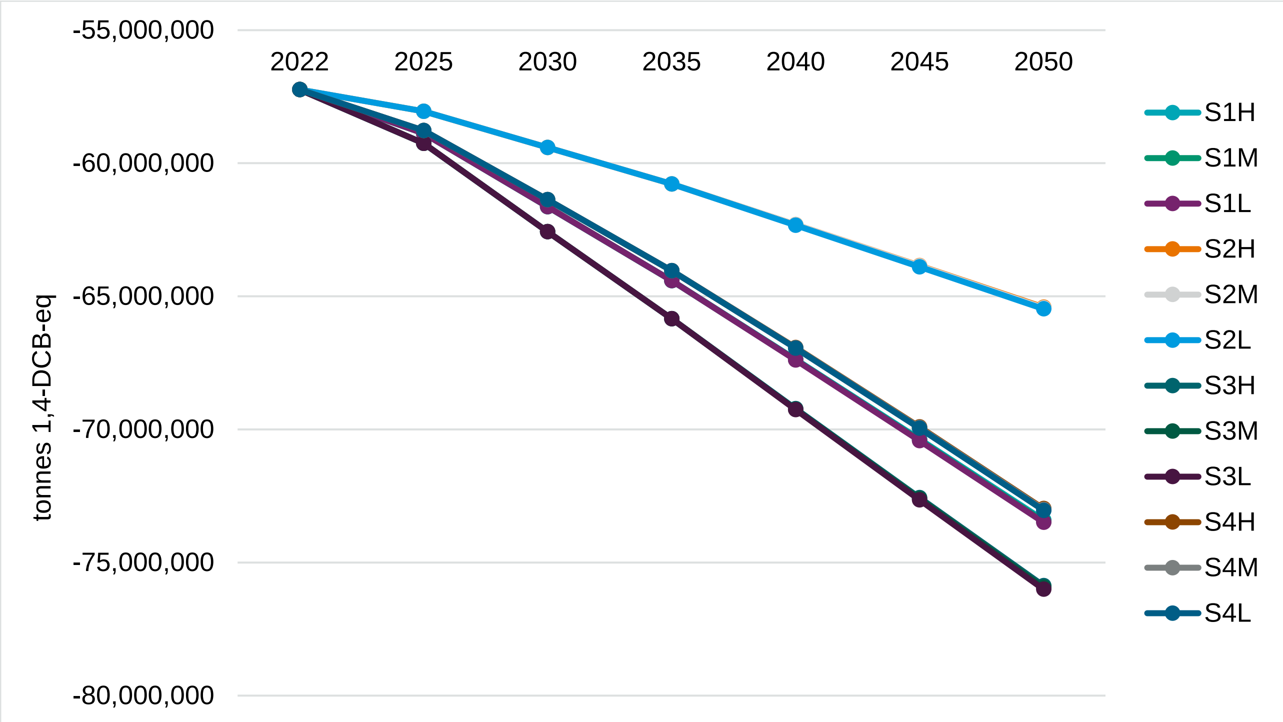


Table 20: Heat map of the human toxicity emissions (tonnes 1,4-DCB-eq) associated with the waste treatment for all scenarios in 2050 - Total is excluding 'Other Bulking'.

2050	S1L	S1M	S1H	S2L	S2M	S2H	S3L	S3M	S3H	S4L	S4M	S4H
Landfill	24,207	24,207	24,207	20,059	20,059	20,059	21,616	21,616	21,616	20,678	20,678	20,678
EfW	-16,091	-13,592	-11,511	-14,071	-11,899	-11,176	-25,381	-21,258	-17,589	-14,985	-12,749	-10,618
EfW with CCS	-44,565	-28,580	-18,514	-39,603	-26,593	-26,264	-83,584	-57,174	-33,410	-51,646	-36,253	-21,490
MBT	-705,045	-710,836	-719,092	-627,790	-632,947	-640,298	-719,656	-719,656	-719,656	-707,809	-707,809	-707,809
MRF	-73,178,977	-73,172,696	-73,166,928	-65,195,073	-65,189,481	-65,187,371	-75,692,712	-75,683,304	-75,675,072	-72,572,414	-72,568,359	-72,564,811
Other Bulking	104,733	104,733	104,733	89,092	89,092	89,092	107,144	107,144	107,144	85,379	85,379	85,379
Composting	270,637	270,637	270,637	240,978	240,978	240,978	291,663	291,663	291,663	235,057	235,057	235,057
AD	171,651	193,393	232,289	152,840	176,048	206,833	214,990	247,468	274,533	65,626	75,540	83,801
ATT	-9,399	-9,399	-9,399	-8,369	-8,369	-8,369	-10,055	-10,055	-10,055	-9,168	-9,168	-9,168
Total	-73,487,583	-73,446,866	-73,398,312	-65,471,029	-65,432,203	-65,405,607	-76,003,120	-75,930,701	-75,867,971	-73,034,661	-73,003,064	-72,974,361

Figure 36 shows that all the waste treatment infrastructure types have a saving of around 57Mt of 1,4-DCB$_{eq}$ in 2022 and the offset in emissions continues to 2050 resulting in around 65Mt to 73Mt saved 1,4-DCB$_{eq}$ emissions by 2050, as seen in Table 20. The savings originate from the recyclables managed in the MRF as it offsets virgin production of commodities. The emissions associated with human toxicity are found in the landfill, other bulking, composting and AD treatment. The biggest saving can be found in either Scenario 1 or 4.

4.3.6 Depletion of Abiotic Resources

Figure 37: Comparison of depletion of abiotic resources potential per scenario

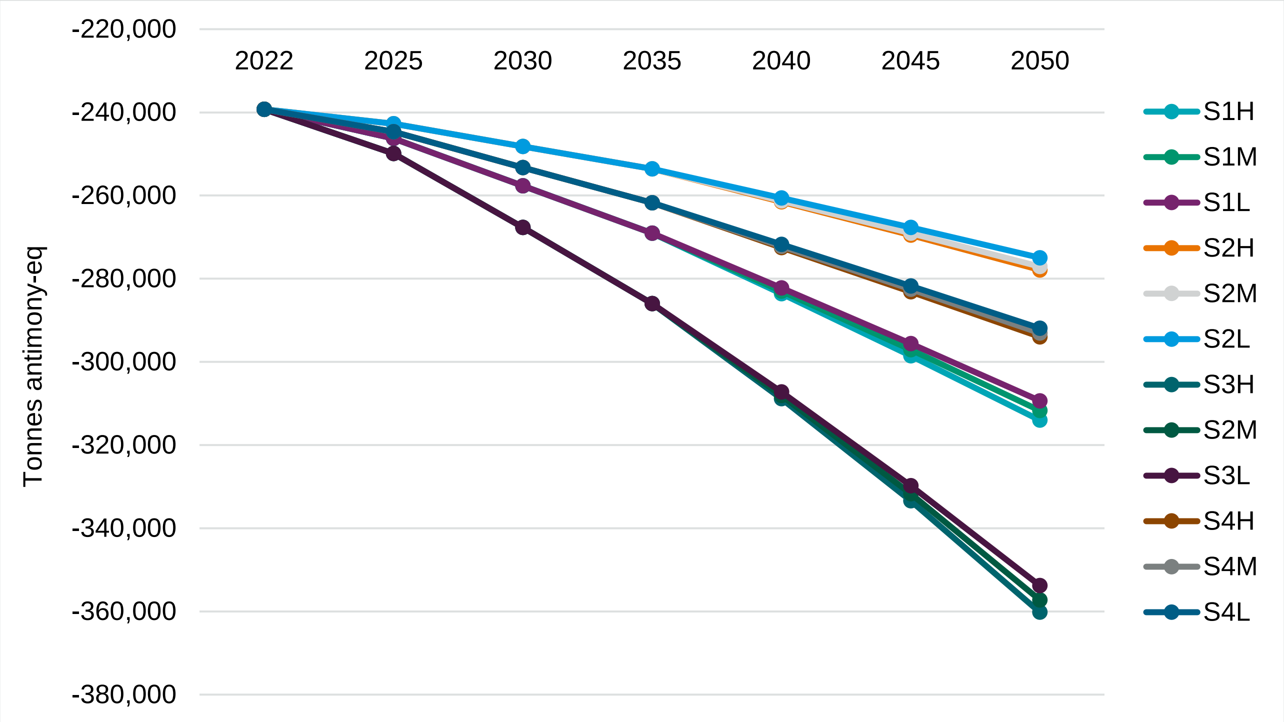


Table 21: Heat map of the depletion of abiotic resource emissions (tonnes antimony-eq) associated with the waste treatment for all scenarios in 2050 - Total is excluding ‘Other Bulking’.

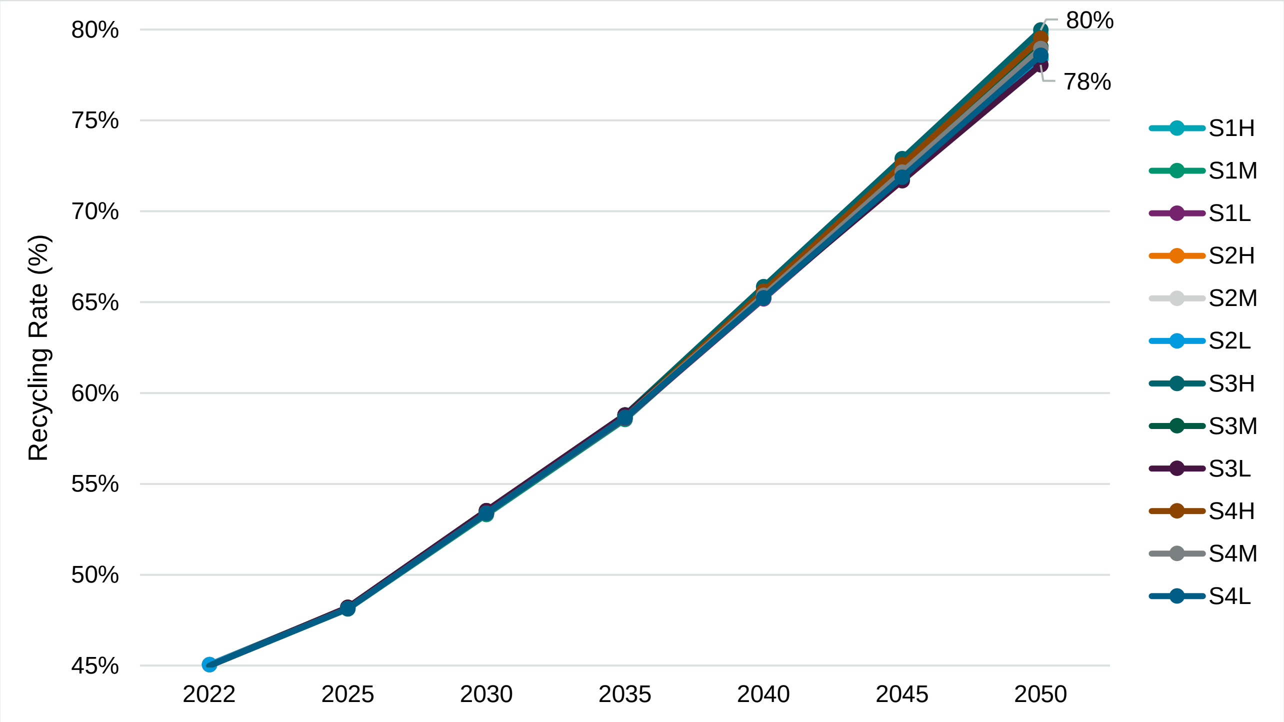
2050	S1L	S1M	S1H	S2L	S2M	S2H	S3L	S3M	S3H	S4L	S4M	S4H
Landfill	-183	-183	-183	-151	-151	-151	-162	-162	-162	-155	-155	-155
EfW	-2,072	-1,865	-1,660	-1,804	-1,615	-1,512	-3,142	-2,800	-2,498	-1,850	-1,676	-1,512
EfW with CCS	-16,095	-14,366	-12,715	-14,329	-12,768	-11,992	-19,267	-16,411	-13,885	-14,501	-13,028	-11,634
MBT	-1,594	-1,460	-1,318	-1,420	-1,300	-1,173	-1,929	-1,929	-1,929	-1,456	-1,456	-1,456
MRF	-281,742	-285,893	-289,706	-250,437	-254,134	-255,528	-320,884	-327,103	-332,545	-267,673	-270,353	-272,698
Other Bulking	1,983	1,983	1,983	1,687	1,687	1,687	2,028	2,028	2,028	1,616	1,616	1,616
Composting	-4,831	-4,831	-4,831	-4,301	-4,301	-4,301	-4,980	-4,980	-4,980	-4,826	-4,826	-4,826
AD	-2,217	-2,497	-3,000	-1,974	-2,273	-2,671	-2,776	-3,196	-3,545	-847	-975	-1,082
ATT	-609	-609	-609	-542	-542	-542	-650	-650	-650	-591	-591	-591
Total	-309,343	-311,705	-314,021	-274,958	-277,085	-277,871	-353,791	-357,230	-360,194	-291,899	-293,061	-293,954

Figure 37 shows that all the waste treatment infrastructure types have a saving of around 240kt of Antimony$_{eq}$ in 2022 and the offset in emissions continues to 2050 resulting in around 275kt to 320kt saved Antimony$_{eq}$ emissions by 2050, as seen in Table 21. The savings originates from the recyclables managed in the MRF as it offsets virgin production of commodities. The biggest savings are found in Scenario 1 and 3.

4.4 RECYLING RATE

The total estimated recycling rate results modelled are displayed in Figure 38.

Figure 38: Estimated total recycling rate



In each scenario, the recycling rate increases from the baseline rate of 45%. Recycling rates rise to 53-54% by 2030 and to 78-80% by 2050. As would be expected, the 'High' recycling rate scenarios: S1H, S2H and S3H, reach the highest estimated recycling rate of 80%. The lowest recycling rate in 2050 of 78% is expected in scenarios S1L, S2M, S2L and S3L.

5. CONCLUSIONS

5.1 NET ZERO PATHWAYS

The main conclusions we have drawn from the Net Zero Pathway results are:

Infrastructure

- The tonnage of waste being sent to landfill is estimated to decline year on year across all scenarios from the baseline of approximately 43Mt, because of the diversion of materials away from landfill to other treatment routes in line with the policy assumptions. In 2050 the highest tonnage estimated to be sent to landfill is 10Mt from scenario 1.
- With the diversion of materials away from landfill and EfW, larger quantities of materials will need to be recycled, resulting in greater demand for MRF capacity. However as previously discussed, MRFs can take many forms, and this is not just for the treatment of DMR. Waste treatment facilities falling into this general category include C&I and C&D processing facilities, end-of-life vehicles (ELV) recycling, food waste pre-treatment facilities, used cooking oil facilities, organic waste pre-treatment facilities, bulking and baling sites and more. Therefore, further analysis would be recommended to establish the waste streams requiring treatment to ensure the right mix and capacity of infrastructure is developed to account for an increase in materials to be recycled.
- The results of the NZP modelling show the use of MRF increasing significantly over the time period. As described above, MRFs as listed in the WDI data cover a wide range of feedstocks, and several MRFs may be required to process a material stream to meet end of waste status. This is why the MRF capacity and cost rises so significantly over the time period. An example of this is plastic recycling which involves a number of stages; separating plastics out of mixed recyclables, then sorting by type and colour before flaking and pelletising ready for recycling. This is rarely carried out at a single facility. As a result, the ambition to divert more plastic from landfill/EfW may result in a requirement of multiple mechanical recycling facilities being built to process the same tonnage.
- Over the projected period, MRF capacity is modelled to increase from the baseline of approximately 51Mt to the following quantities in 2035 and 2050.

Scenario	2035 Capacity	2050 Capacity
Scenario 1	80Mt	127Mt
Scenario 2	73Mt	108Mt
Scenario 3	79Mt	125Mt
Scenario 4	74Mt	110Mt

In 2035 therefore, the estimated additional capacity requirements under the lowest scenario are 22Mt and an estimated 29Mt under the highest scenario. By 2050, a further 57Mt under the lowest scenario and 76Mt under the highest scenario will be required. This high-level estimate assumes that the current baseline capacity remains, whereas it would be expected that facilities will reach the end of their life and close or require investment to ensure they remain operating effectively and efficiently.

The forecasted capacity requirements for the core materials of a DMR (dry mixed recycling) MRF are shown in the below table, these capacity tonnes are the total for glass, metallic wastes, paper and cardboard, and plastics.

Scenario	2035 Capacity	2050 Capacity
1	22M	26M
2	21M	23M
3	24M	32M
4	21M	23M

The capex investment for new MRFs will vary widely based upon factors such as the technology type, automation, tonnage/throughput and specific material streams. A high-level capex cost estimate for the low and high capacity requirements in 2035 would be estimated to be in the range of £7 to £9 billion. In 2050, this estimated capex cost would be in the range of £17 to £23 billion. This capex cost has been estimated using a current price per tonne assumption and is therefore the current forecast cost, as it does not include future inflation for example.

- Over the projected period, AD capacity requirements vary over the four scenarios. The baseline AD capacity requirement modelled is approximately 3Mt which increases to the following quantities in 2035 and 2050 outlined in the following table for each scenario.

Scenario	2035 Capacity	2050 Capacity
Scenario 1	4Mt	6Mt
Scenario 2	4Mt	5Mt
Scenario 3	5Mt	6Mt
Scenario 4	4Mt	4Mt

In 2035 therefore, the estimated additional capacity requirements under the lowest scenario are 1Mt and 2Mt under the highest scenario. In 2050 the lowest additional capacity requirements are approximately 1Mt under the scenario that there are lower waste arisings and lower quantities or organic material within the waste system. However, the highest additional capacity requirements would be 3Mt under the scenario where there are higher arisings and higher quantities of organic wastes. This high-level estimate is again on the assumption that the current baseline capacity remains available.

A high-level current capex cost estimate for the low and high capacity requirements in 2035 would be in the range £190 to £380 million. In 2050, this capex cost would be in the range of £190 to £570 million. Again, this estimate has used current costs and not factored in any measures such as inflation.

- The baseline composting capacity of 5Mt is estimated to increase within scenarios 1 and 3 where there are higher waste arisings in both scenarios and higher organic waste composition in scenario 3. The largest capacity demand exists under scenario 3 which equates to 7Mt in the year 2050.

  A high-level capex cost estimate for the additional 2Mt of capacity would result in approximately £50 million. This again has used current costs and not factored in any measures such as inflation.

- EfW capacity is modelled to reduce from the baseline capacity of approximately 17Mt under all modelled scenarios. EfW with CCS transitions with capacity modelled to become available in 2030. The table below shows the estimated capacity requirements in 2042 where there is the target to achieve a 50% reduction in residual waste being sent to landfill and EfW, and 2050.

Scenario	2042 Capacity			2050 Capacity		
Facility Type	EfW	EfW CCS	*Total*	EfW	EfW CCS	*Total*
Scenario 1	7Mt	7Mt	*14Mt*	1Mt	11Mt	*12Mt*
Scenario 2	7Mt	6Mt	*13Mt*	1Mt	9Mt	*10Mt*
Scenario 3	9Mt	7Mt	*16Mt*	4Mt	10Mt	*14Mt*
Scenario 4	6Mt	6Mt	*12Mt*	1Mt	8Mt	*9Mt*

The estimated capacity requirements for EfW in 2042 (including both EfW and EfW with CCS) in the lowest scenario are approximately 12Mt (scenario 4). The highest capacity requirements are approximately 16Mt (scenario 3). In 2050 the lowest capacity requirements are approximately 9Mt and highest requirements approximately 14Mt under the same scenarios.

We recommend that further analysis is undertaken to establish when current EfW capacity is likely to close and the current capacity in the pipeline (i.e., that which is in planning, construction, commissioning etc.). EfW facilities have a long lifespan and there is a danger that both scenarios of over and under capacity could develop if not managed and closely tracked against the success of policy targets. This review will also need to consider factors such as long-term local authority contracts which could be 'locked in' with current treatment routes for long periods of time.

- The assessment has focussed upon England at a national level, therefore more regional waste quantities and corresponding capacity requirements have not been considered. Future infrastructure development should consider the proximity principle where possible which will also potentially support wider emissions reductions through reducing waste transportation distances.

Emissions

- Under the modelled NZPs carbon emissions reduce by approximately 80% in all four scenarios. This transition is predominantly driven by the diversion of waste away from landfill and EfW, with EfW facilities further transitioning to incorporate CCS. This equates to a reduction from the baseline year total of approximately 16Mt CO2-e, to 3Mt CO2-e in 2050 in scenarios 1, 2, 4, and 4Mt CO2-e in scenario 3.
- Within the four modelled NZP scenarios, net zero is not achieved in 2050 due primarily to the carbon scope examined (i.e., only scope 1). Since the scope of the analysis is limited to direct emissions from decomposition and incineration (as mentioned in section 3.2), and in all four scenarios, there remains some waste going to facilities that emit direct emissions (AD, Composting, MBT, Landfill, EfW), it is not possible to achieve net zero. If the analysis were to include the benefits of avoided emissions (scopes 3 and 4) these benefits would outweigh the Scope 1 and 2 emissions, i.e., there would be a net carbon benefit. However, to maintain alignment with Government targets, these benefits cannot be included. Previous analysis conducted by Ricardo for the Environmental Services Association (ESA)[50], shows that within the UK waste industry, emissions avoided by the diversion of waste to recycling offsets all scope 1 and 2 carbon emissions.
- The government is incentivising the development of EfW with CCS technologies to help de-carbonise the technology. The roll out of this is likely to take many years, and a conservative estimate that 90% of facilities will have CCS by 2050 has been applied. However, EfW facilities with CCS are still estimated to have some net positive emissions, though on a much-reduced scale compared to facilities without CCS. In the NZP modelling, it has been assumed that the addition of CCS technologies reduces emissions by 85%. The emissions reduction shown over time is therefore dependent upon the uptake and development of CCS technology and is one of the key factors in the decarbonisation journey.

Costs

- The cost analysis carried out in this study is indicative only and should be treated as a guide. It is challenging to produce a single cost figure for a certain treatment technology as there are a myriad of factors which can impact the development cost. These include elements such as site location, ground conditions and geological features, local labour/material costs, scale of the facility, quality of input and output materials, technology used and many more.
- The costs show that the largest investment will need to be in MRF technologies which aligns with the increase in the use of this type of facility. Bulking facilities are typically cheap as they do not require any complicated process technology, and as such the cost associated with those is relatively static. The cost of EfW development will increase over the years due to the increasing requirement to include CCS within the facility. The average cost per tonne of EfW across the scenarios is approximately £255 compared to EfW with CCS at £332. As a result, the total cost of development of an EfW plant which includes CCS will be higher than the current cost of EfW development without it, as is reflected in the cost scenario for EfW + CCS.
- A high-level current cost estimate for the low and high-capacity requirements of EfW in 2035 would be estimated to be in the range of £2 to £3 billion, and for EfW with CCS in the range of £700 to £1000 million. In 2050, this estimated cost would be in the range of £200 to £920 million for EfW, and for EfW with CCS in the range of £2.5 to £4 billion. Again, these estimates have used current costs and not factored in any measures such as inflation.
- The costs modelling does not currently consider EfW in any future ETS. This has not been included due to the current uncertainty about its implementation. However, this should be revised at the next

[50] https://www.esauk.org/application/files/7816/2911/4009/ESA_GHG_Quantification_Final_Report_23_06_2020_Issued.pdf

infrastructure assessment once further details have been confirmed as it is likely to impact on the cost mechanisms for EfW facilities.

- As an example of the uncertainty, in a published report, Tolvik (2022)[51] assumed an average gate fee of £93 per tonne for residual waste being sent to EfW. With a further assumption of 19.4Mt being treated at EfW facilities resulting in a total gate fee income of over £1.8bn. Tolvik estimated that the total ETS carbon cost would be 23-43% of this total, based upon an assumed fossil content composition of 48% and an average CO2 emitted factor of 0.992tCO2 per tonne of waste input. On the assumption that EfW facilities simply pass this cost on fully to waste suppliers, Tolvik indicate that this could result in suppliers being liable for approximately £0.3 to £0.6bn in additional costs. Tolvik also noted that most of these costs are likely to be passed to local authorities, who are large providers of residual waste to EfW facilities. Tolvik also considered the complexity of Extended Producer Responsibility (EPR) schemes being consulted on by Defra. It is likely that EPR will need to manage packaging waste being produced by brands which makes up a proportion of the residual waste stream. This will therefore add a potential further complexity as to whether ETS costs should flow back to and be considered within any EPR scheme and in part providing some compensation to local authorities.
- Any additional costs at EfW facilities will need to consider unintended consequences such as the impact upon other treatment routes. For example, if landfill tax does not increase and biodegradable waste to landfill bans are not implemented. Could this result in increased quantities of waste being sent to landfill? Equally, could waste exports increase?

5.2 ENHANCED CIRCULARITY PATHWAYS

The evidence base provided within this report shows that the main conclusions of the enhanced circularity pathway results are:

Infrastructure and costs

- The tonnage of waste being sent to landfill is estimated to decline year on year across all scenarios and recycling rate options from the baseline of an approximate 43Mt. In 2050 the highest tonnage estimated to be sent to landfill is 10Mt from scenario 1 (low, medium, high).
- With the diversion of materials away from landfill and EfW, larger quantities of materials will need to be recycled, resulting in a need for increased MRF capacity. This is especially needed to reach the higher circularity targets of the priority materials identified. The results of the ECP modelling show the use of MRF increasing significantly across all scenarios and recycling rate options.

  Therefore, by 2050, this equates to a total capacity of 129Mt under the highest recycling rate for the highest scenario, an increase of approximately 2Mt over the high NZP scenario, and 108Mt for the lowest recycling rate in the lowest scenario. This high-level estimate is on the assumption that the current baseline capacity remains, whereas it would be expected that facilities will reach the end of their life and close or require investment to ensure they continue to operate effectively and efficiently.

  The capex investment for new MRFs will vary widely, based upon factors such as the technology type, automation, tonnage/throughput, and specific material streams. A high-level capex cost estimate for the low scenario and low recycling rate option and high scenario, high recycling option capacity requirements in 2050 would be estimated to be in the range of £11 to £23 billion. This capex cost has been estimated using a current price per tonne assumption and is therefore the current forecast cost, as it does not include future inflation for example.
- Over the projected period, AD capacity requirements vary over the four scenarios and recycling rate options. The baseline AD capacity requirement modelled is approximately 3Mt which by 2050 increases for the lowest scenario and recycling rate option to 4.2Mt. However, the highest total capacity requirements would be 8Mt under S3H, the scenario where there are higher arisings, higher quantities of organic wastes, and higher recycling rate levels required to reach the target circularity. This is an increase of approximately 2Mt over the scenario 3 NZP. This high-level estimate is again on the assumption that the current baseline capacity remains available.

[51] https://www.tolvik.com/published-reports/view/response-to-call-for-evidence-on-inclusion-of-efw-in-the-uk-emissions-trading-scheme/

A high-level current capex cost estimate for the low and high-capacity requirements in 2035 would be estimated to be in the range £190 to £380 million. In 2050, this estimated capex cost would be in the range of £190 to £570 million. Again, this estimate has used current costs and not factored in any measures such as inflation.

- The baseline composting capacity of 5Mt is estimated to increase across the scenarios and recycling rate options. The largest capacity demand is under scenario 3 which equates to an estimated total of 6.5Mt across the circularity options in the year 2050.

  A high-level capex cost estimate would result in approximately £50 million. This estimate again has used current costs and not factored in any measures such as inflation.

  EfW capacity is modelled to reduce from the baseline capacity of approximately 17Mt under all modelled scenarios and recycling rate options. EfW with CCS transitions with capacity modelled to become available in 2030. In 2050 the required capacity for EfW is estimated to be between 0.8Mt to 2Mt, and EfW with CCS capacity requirements between 7Mt to 11Mt by 2050.

Environmental Impacts

In general, the lowest impacts on acidification, eutrophication, human toxicology, freshwater aquatic ecotoxicology, and depletion of abiotic resources, are seen within scenarios 1 and 4.

Those five environmental impact categories consider scopes 1, 2 and 3. Thus, they are offsetting the production of virgin materials resulting in reduced emissions. Scenario 2 and 4's low options are generating the lowest amount of CO2e emissions. This highlights how waste quantity is the driving factor of CO2e emissions. It should be noted that the GWP is only considering Scope 1 emissions and is not offsetting any emissions saved by the recycled materials substituting virgin material demand.

- The impact on the global warming potential reduces by approximately 13Mt CO2e between 2022 and 2050. This is because of diverting waste from landfill and EfW, with and without CCS, up the waste management hierarchy to recycling.
- The results show that Scenario 2 and 4 has the lowest impacts with the high recycling options resulting in the lowest amount of emissions among the three options. This shows that the factor dominating the impacts on the emissions is the amount of tonnage treated in the scenarios, with more waste being diverted resulting in fever emissions being emitted during the processing of the waste. This analysis is not taking offset of virgin production into consideration and thus this result shows the difference in emissions generated by processing the waste. If the offset virgin materials were to be included the results of this analysis could change, with the high waste arising scenarios also generating more materials which can be used to substitute virgin materials.
- The impact of acidification results shows that scenario 3 has the biggest reduction in tonnes SO2-eq These results include all three scopes, therefore they are accounting for the offset materials resulting in a saving, generated in MRF and the MBT facilities, with the other waste treatment facilities generating emissions during waste treatment. Because of this scenario 3 has the biggest saving as it is diverting the most materials towards recycling, thus substituting virgin materials.
- For eutrophication, scenario 4 brings the biggest overall saving towards the impacts of eutrophication on the environment. Again, this is a result of the increased tonnes to MRF diverting materials up the waste hierarchy away from landfill and EfW resulting in virgin materials being substituted.
- The results of the freshwater aquatic ecotoxicology show scenario 3 is yielding the biggest saving of approximately 6,000 tonnes 1,4-DCB_e in 2050. Here the EfW, with and without CCS, and ATT facilities are providing a reduction of the emissions in addition to MBT and MRF. Other bulking, AD and Landfill are generating the most emissions towards freshwater aquatic ecotoxicology during the management of the waste. Notably, the AD facility is emitting more 1,4-DCB_e in the high options when compared to the low options.
- The biggest benefit to the impact category human toxicology is seen in scenario 3. ATT, EfW, with and without CCS, are reducing emissions for this impact category because of the materials not decomposing in landfills, composting, or AD. Scenario 3 low has the biggest potential benefit with a saving of around 76Mt 1,4-DCB_e.
- For the depletion of abiotic resources, scenario 3 has the biggest potential offsetting of $antimony_{eq}$ by 2050. This saving can be obtained in all treatment methods; however, the magnitude of the savings shows a clear picture that recycling is most impactful way to reduce the depletion of abiotic resources.

The MRF accounts for offsetting around 90% of the resources impacts therefore the scenario and option where the highest amount of waste is being recycled, the lower the impacts.

APPENDIX 1 - GLOSSARY OF KEY TERMS

Term	Definition
Acidification potential	The impact of the activities on the potential for acid rain in England.
AD	Anaerobic Digestion, waste treatment facility type in which organic waste is broken down in the absence of oxygen.
ATT	Advanced Thermal Treatment, waste treatment facility employing pyrolysis and/or gasification to process waste.
C&D	Construction and Demolition Waste, represents waste classed under 'Chapter 17 – C&D Waste' within the Environment Agency's waste data interrogator.
C&I	Commercial and Industrial Waste, waste classed within the Environment Agency's waste data interrogator excluding Chapters 17 and 20.
Capex	Capital Expenditure
Depletion of abiotic resources potential	The impact of the activities on the amount of resources available in the environment, using antimony as a proxy.
EfW with CCS	Energy from Waste facility with Carbon Capture and Storage technologies
Eutrophication potential	The impact of the activities on the amount of phosphate in surface water systems.
Freshwater aquatic ecotoxicity potential	The impact of the activities on the amounts of potentially polluting substances that could harm aquatic life.
Human toxicity potential	The impact of the activities on the amounts of substances that are potentially toxic to humans. This is measured in terms of tonnes of dichlorobenzene equivalent as a measure of toxins emitted by the facilities.
LACW	Local Authority Collected Waste, represents waste classed under 'Chapter 20 – Municipal Wastes' within the Environment Agency's waste data interrogator.
MBT	Mechanical Biological Treatment facility
MRF	Material Recycling Facility, represents all mechanical recycling including aggregate recycling, metal reprocessing, wood recycling and many other processes. Due to the reporting method in the WDI, this facility type also includes some organic waste recycling such as cooking oil recycling, composting pre-treatment, and others. Additionally, this facility type represents both the initial stage of sorting recyclate as well as downstream processing to prepare materials for manufacturing
Opex	Operational Expenditure

Term	Definition
Other Bulking	Represents waste going through transfer stations.
Recovery	As defined by the EU Waste Framework Directive, any operation the principal result of which is waste serving a useful purpose by replacing other materials which would otherwise have been used to fulfil a particular function, or waste being prepared to fulfil that function, in the plant or in the wider economy.

APPENDIX 2 - ASSUMPTION FACTORS

Table A 1: Carbon Emission Factor Assumptions

Waste Categories	Landfill	EfW	MBT	MRF	Other Bulking	Compost	AD	ATT	Recycling	EfW with CCS
Acid, alkaline or saline wastes	0.000	0.824						0.411		0.124
Animal and mixed food waste	0.646	0.000	0.197			0.172	0.020	0.411		0.000
Animal faeces, urine and manure	0.704	0.563	0.197			0.172	0.020	0.411		0.084
Batteries and accumulators wastes	0.000	0.824						0.411		0.124
Chemical wastes	0.000	0.824						0.411		0.124
Combustion wastes	0.000	0.103						0.411		0.015
Common sludges	0.148	0.000						0.411		0.000
Discarded equipment (excluding discarded vehicles, batteries and accumulators waste)	0.000	0.580						0.411		0.087
Discarded vehicles	0.000	0.580						0.411		0.087
Dredging spoils	0.000	0.103						0.411		0.015
Glass wastes	0.000	0.000						0.411		0.000
Health care and biological wastes	0.000	0.256						0.411		0.038
Industrial effluent sludges	0.000	0.103						0.411		0.015
Metallic wastes, ferrous	0.000	0.000						0.411		0.000
Metallic wastes, mixed ferrous and non-ferrous	0.000	0.000						0.411		0.000
Metallic wastes, non-ferrous	0.000	0.000						0.411		0.000

Waste Categories	Landfill	EfW	MBT	MRF	Other Bulking	Compost	AD	ATT	Recycling	EfW with CCS
Mineral waste from construction and demolition	0.021	0.256						0.411		0.038
Mineral wastes from waste treatment and stabilised wastes	0.021	0.256						0.411		0.038
Mixed and undifferentiated materials	0.704	0.563						0.411		0.084
Other mineral wastes	0.021	0.256						0.411		0.038
Paper and cardboard wastes	1.337	0.000	0.197			0.172	0.020	0.411		0.000
Plastic wastes	0.000	2.010						0.411		0.302
Rubber wastes	0.000	0.103						0.411		0.015
Sludges and liquid wastes from waste treatment	0.148	0.000						0.411		0.000
Soils	0.018	0.000						0.411		0.000
Sorting residues	0.665	0.412						0.411		0.062
Spent solvents	0.000	0.824						0.411		0.124
Textile wastes	0.427	0.731						0.411		0.110
Used oils	0.000	0.824						0.411		0.124
Vegetal wastes	0.752	0.000	0.197			0.172	0.020	0.411		0.000
Waste containing PCB	0.000	0.824						0.411		0.124
Wood wastes	1.309	0.000	0.197			0.172		0.411		0.000

Table A 2: Recycling Rate Assumptions

Material Categories	Landfill	EfW	MBT	MRF	Composting	AD	ATT
Acid, alkaline or saline wastes	5%	0%	0%	90%	95%	95%	0%
Animal and mixed food waste	0%	0%	30%	90%	95%	95%	0%
Animal faeces, urine and manure	0%	0%	15%	90%	95%	95%	0%
Batteries and accumulators wastes	0%	0%	0%	90%	95%	95%	0%
Chemical wastes	0%	5%	0%	90%	95%	95%	0%
Combustion wastes	20%	50%	0%	90%	95%	95%	30%

Material Categories	Landfill	EfW	MBT	MRF	Composting	AD	ATT
Common sludges	0%	0%	0%	90%	95%	35%	0%
Discarded equipment (excluding discarded vehicles, batteries and accumulators waste)	0%	60%	0%	90%	95%	95%	0%
Discarded vehicles	80%	0%	0%	90%	95%	95%	0%
Dredging spoils	0%	0%	0%	90%	95%	95%	0%
Glass wastes	0%	20%	60%	90%	95%	95%	0%
Health care and biological wastes	0%	0%	0%	90%	95%	95%	0%
Industrial effluent sludges	0%	0%	0%	90%	95%	70%	0%
Metallic wastes, ferrous	20%	80%	80%	90%	95%	95%	80%
Metallic wastes, mixed ferrous and non-ferrous	0%	20%	50%	90%	95%	95%	20%
Metallic wastes, non-ferrous	30%	80%	80%	90%	95%	95%	80%
Mineral waste from construction and demolition	40%	20%	5%	90%	95%	95%	20%
Mineral wastes from waste treatment and stabilised wastes	70%	0%	0%	90%	95%	95%	0%
Mixed and undifferentiated materials	0%	0%	0%	90%	95%	95%	0%
Other mineral wastes	30%	0%	0%	90%	95%	95%	0%
Paper and cardboard wastes	10%	40%	10%	90%	95%	95%	0%
Plastic wastes	0%	0%	30%	90%	95%	95%	0%
Rubber wastes	0%	0%	0%	90%	95%	95%	0%
Sludges and liquid wastes from waste treatment	20%	0%	0%	90%	95%	95%	0%
Soils	30%	0%	0%	90%	95%	95%	0%
Sorting residues	0%	0%	0%	90%	95%	95%	0%
Spent solvents	0%	0%	0%	90%	95%	95%	0%
Textile wastes	0%	0%	0%	90%	95%	95%	0%
Used oils	0%	0%	0%	90%	95%	95%	0%
Vegetal wastes	0%	0%	0%	90%	90%	85%	0%

Material Categories	Landfill	EfW	MBT	MRF	Composting	AD	ATT
Waste containing PCB	0%	0%	0%	90%	95%	95%	0%
Wood wastes	10%	25%	30%	90%	95%	95%	0%

APPENDIX 3 - SCENARIO TONNES

Tonnage of waste sent to each of the different facility types. over the projected timeline for each of the individual scenario and recycling levels are presented in Figure 39 to Figure 50.

Scenario 1 results are presented in Figure 39 to Figure 41

Figure 39: Scenario 1 (High Arisings – High Recycling) Tonnes per facility type

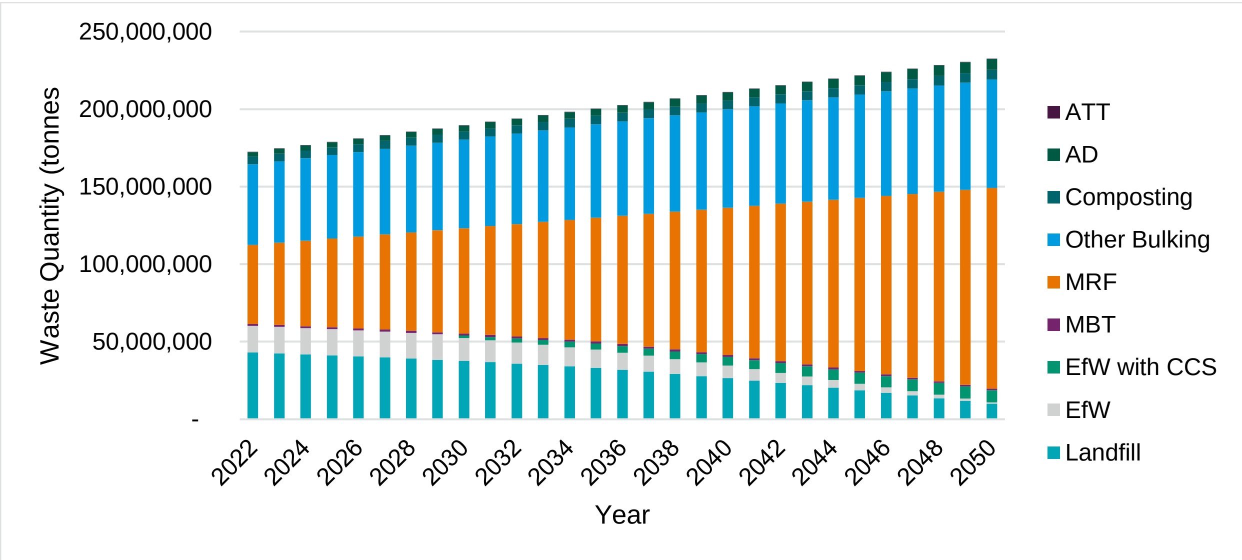


Figure 40: Scenario 1 (High Arisings – Medium Recycling) Tonnes per facility type

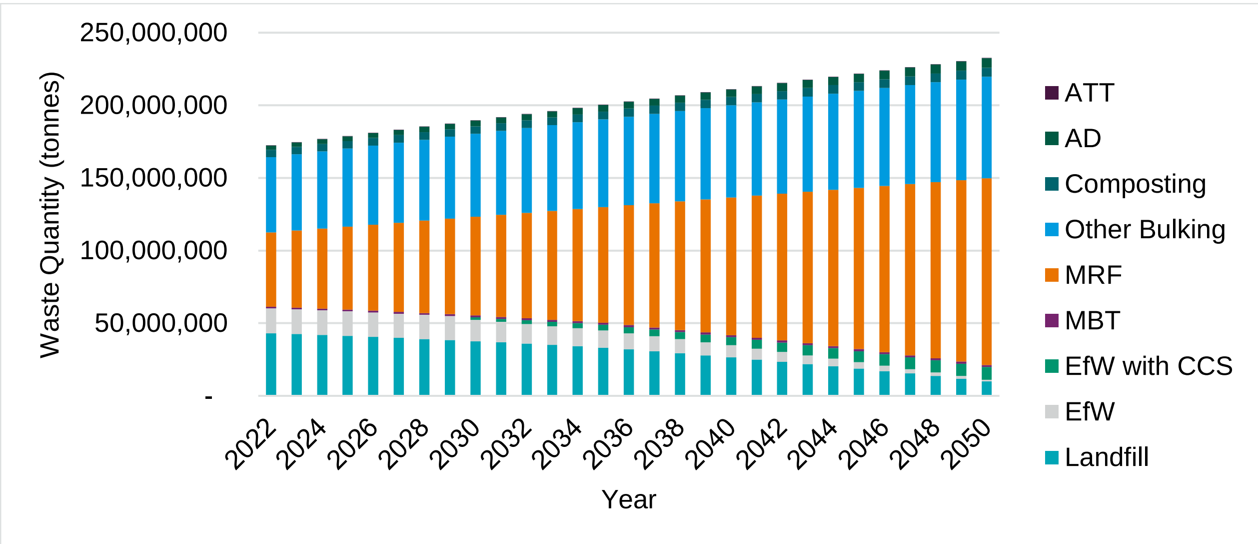
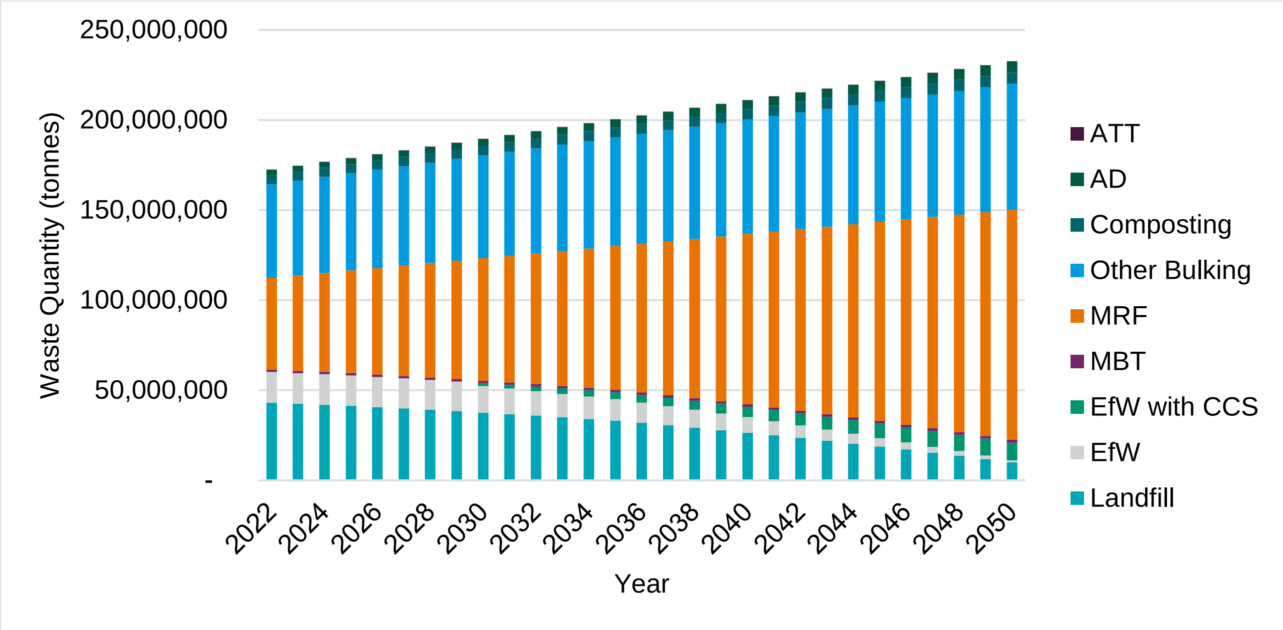


Figure 41: Scenario 1 (High Arisings - Low Recycling) Tonnes per facility type



Scenario 2 results are presented in Figure 42 to Figure 44

Figure 42: Scenario 2 (Low Arisings – High Recycling) Tonnes per facility type

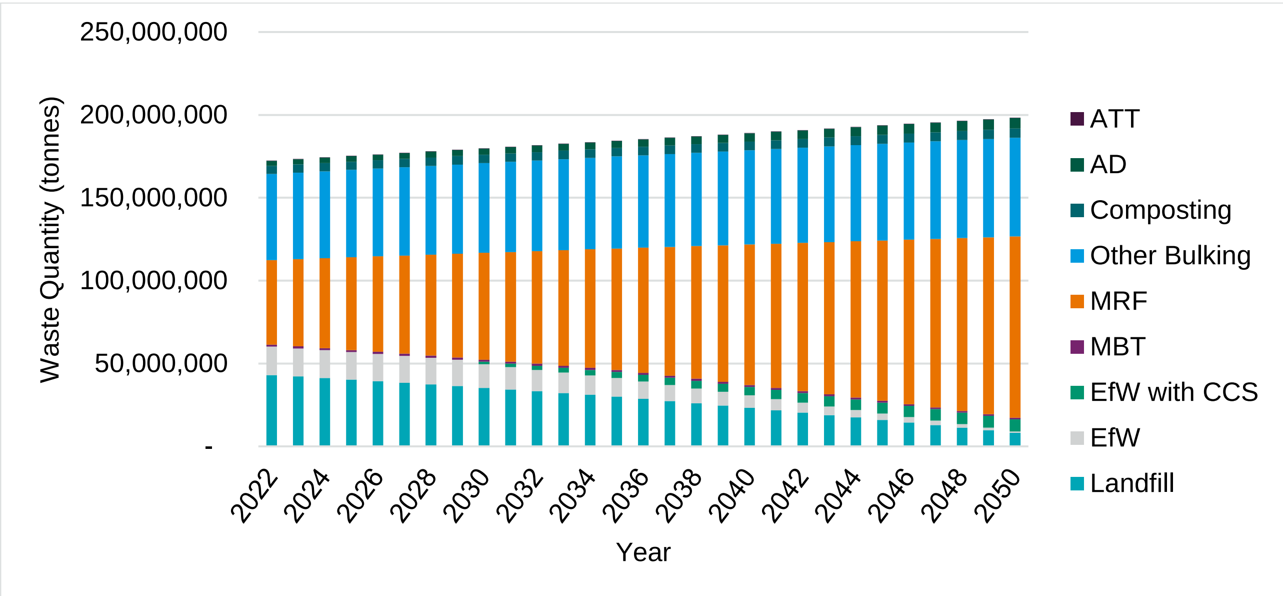


Figure 43: Scenario 2 (Low Arisings - Medium Recycling) Tonnes per facility type

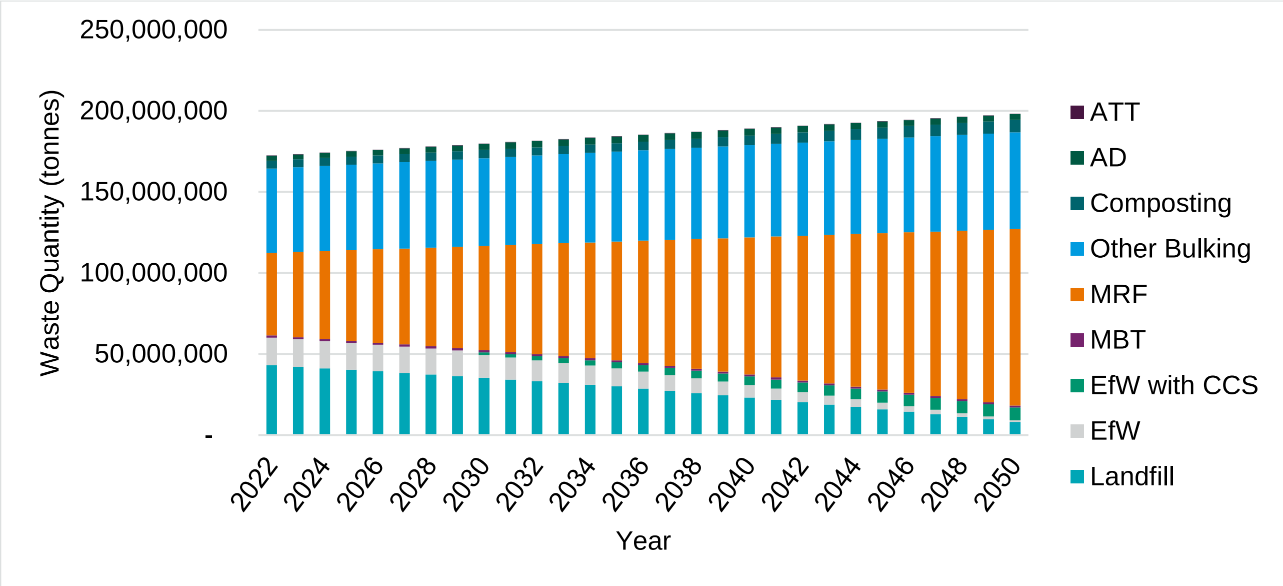
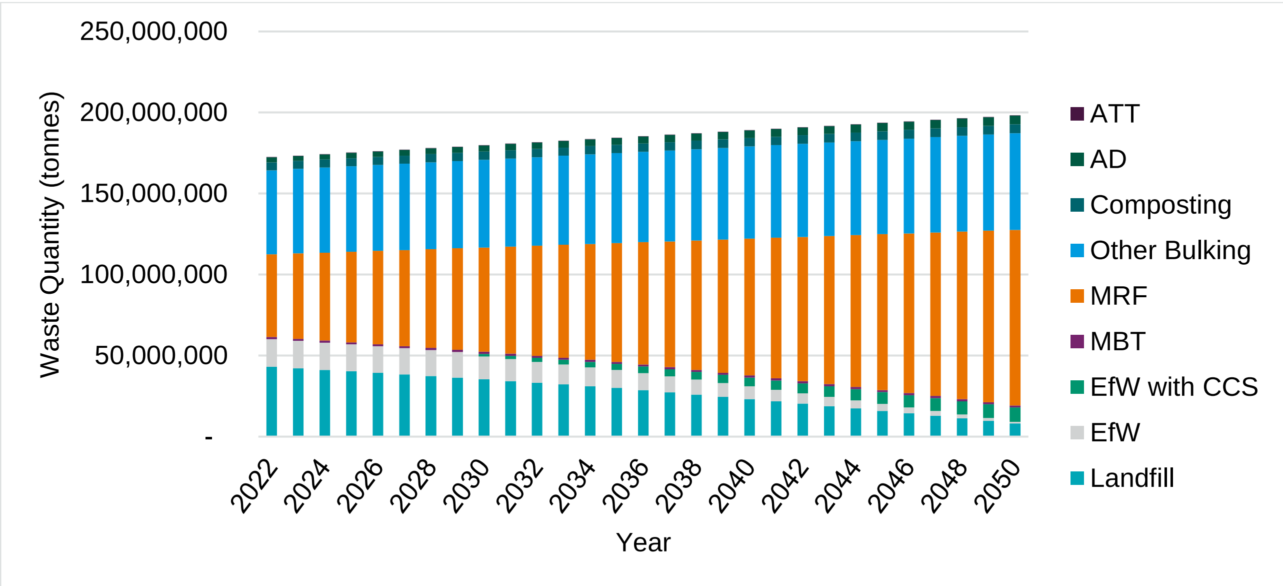


Figure 44: Scenario 2 (Low Arisings - Low Recycling) Tonnes per facility type



Scenario 3 results are presented in Figure 45 to Figure 47.

Figure 45: Scenario 3 (High Composition – High Recycling) Tonnes per facility type

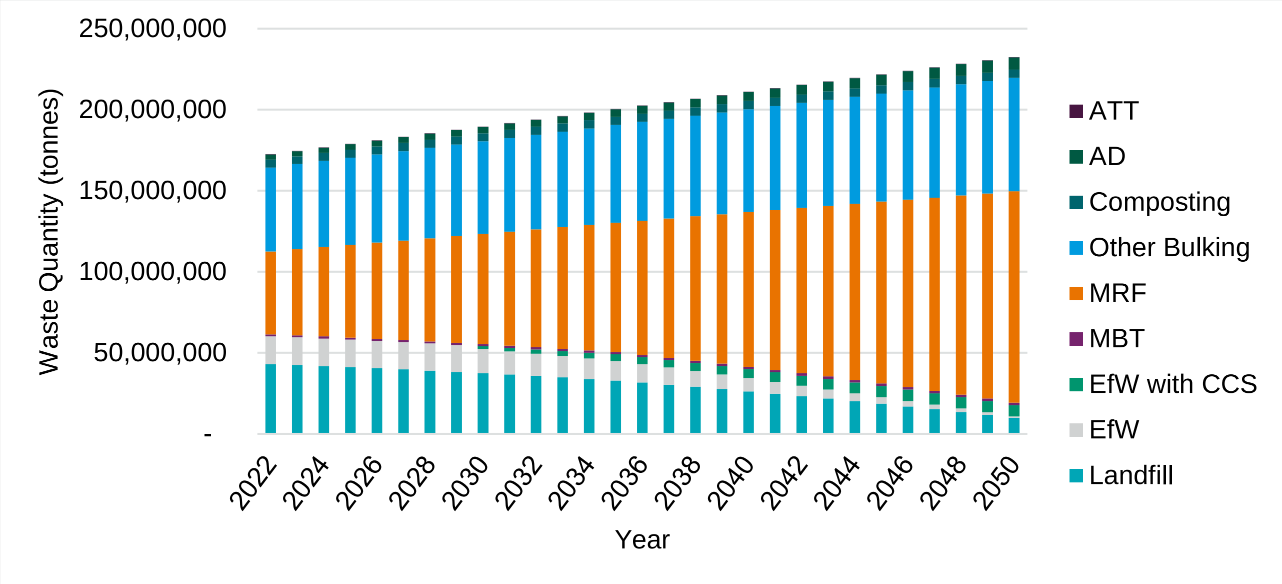


Figure 46: Scenario 3 (High Composition – Medium Recycling) Tonnes per facility type

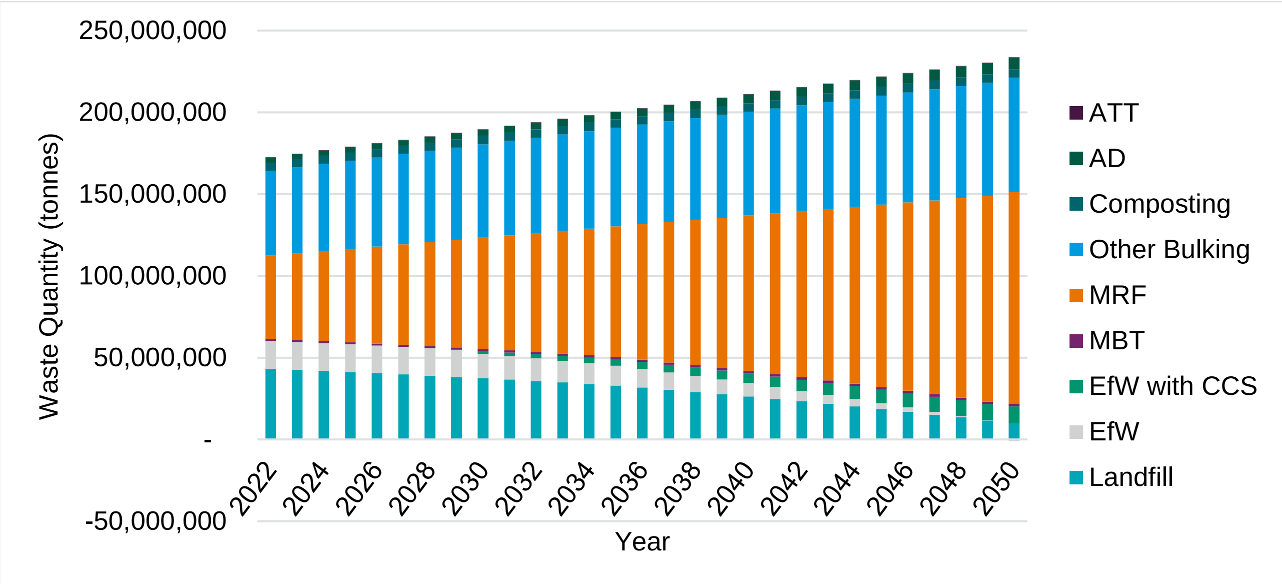
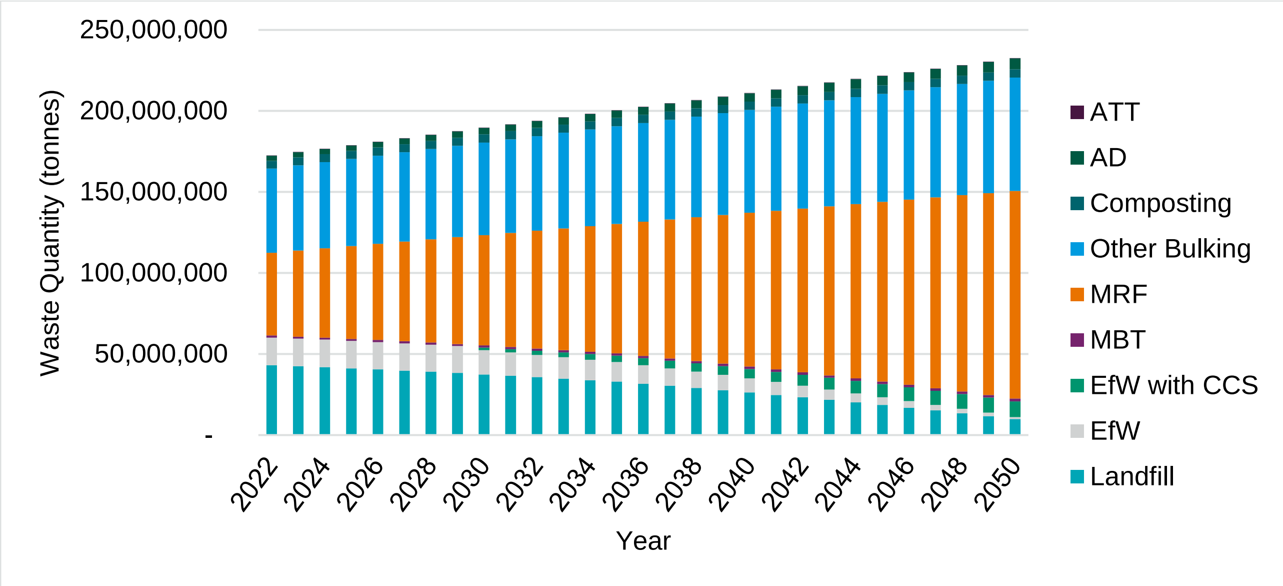


Figure 47: Scenario 3 (High Composition – Low Recycling) Tonnes per facility type



Scenario 4 results are presented in Figure 48 to Figure 50

Figure 48: Scenario 4 (Low Composition – High Recycling) Tonnes per facility type

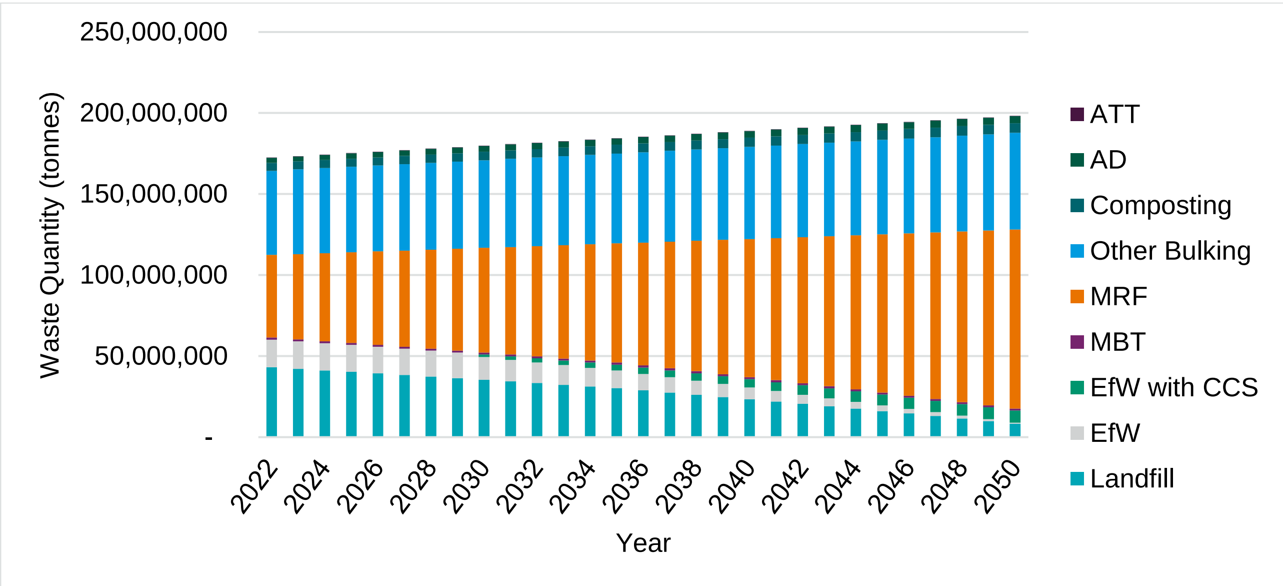


Figure 49: Scenario 4 (Low Composition – Medium Recycling) Tonnes per facility type

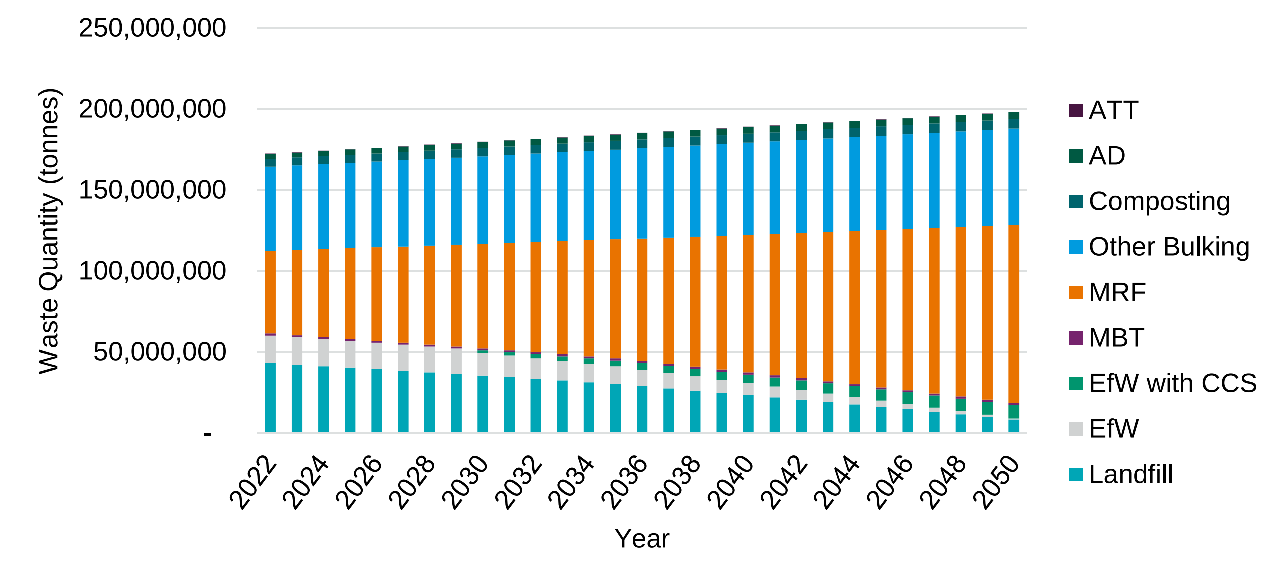
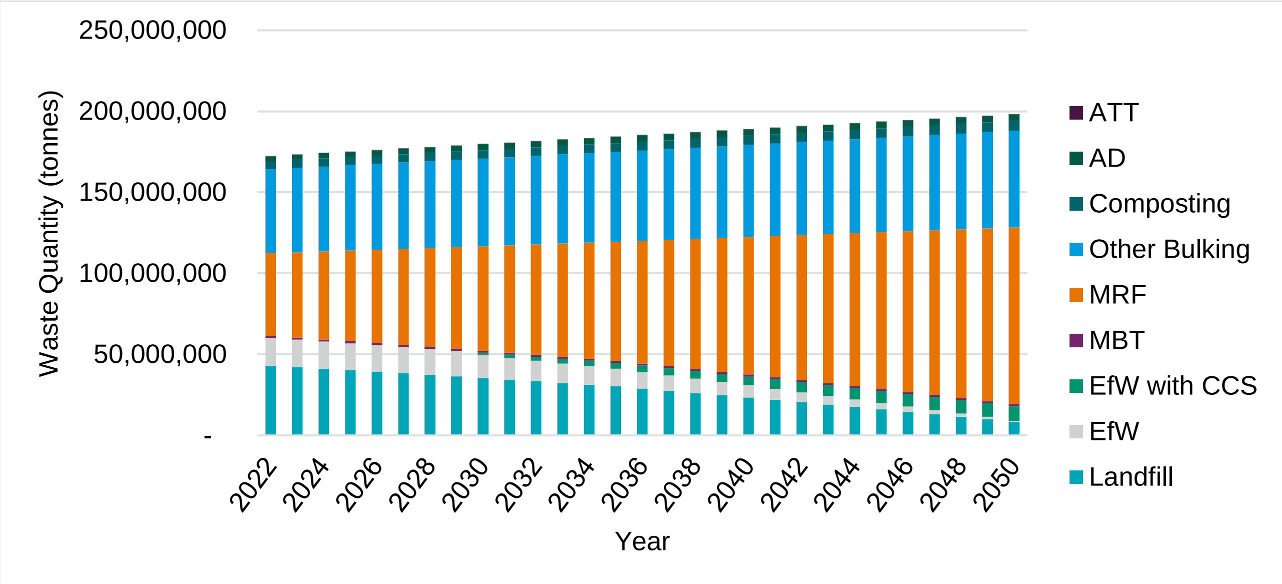


Figure 50: Scenario 4 (Low Composition – Low Recycling) Tonnes per facility type



APPENDIX 4 - SCENARIO COSTS

The cost (capex and opex) for each of the different facility types. over the projected timeline for each of the individual scenario and recycling levels are presented in Figure 51 to Figure 62.

Scenario 1 results are presented in Figure 51 to Figure 53.

Figure 51: Scenario 1 (High Arisings – High Recycling) Cost per facility type (Capex + Opex)

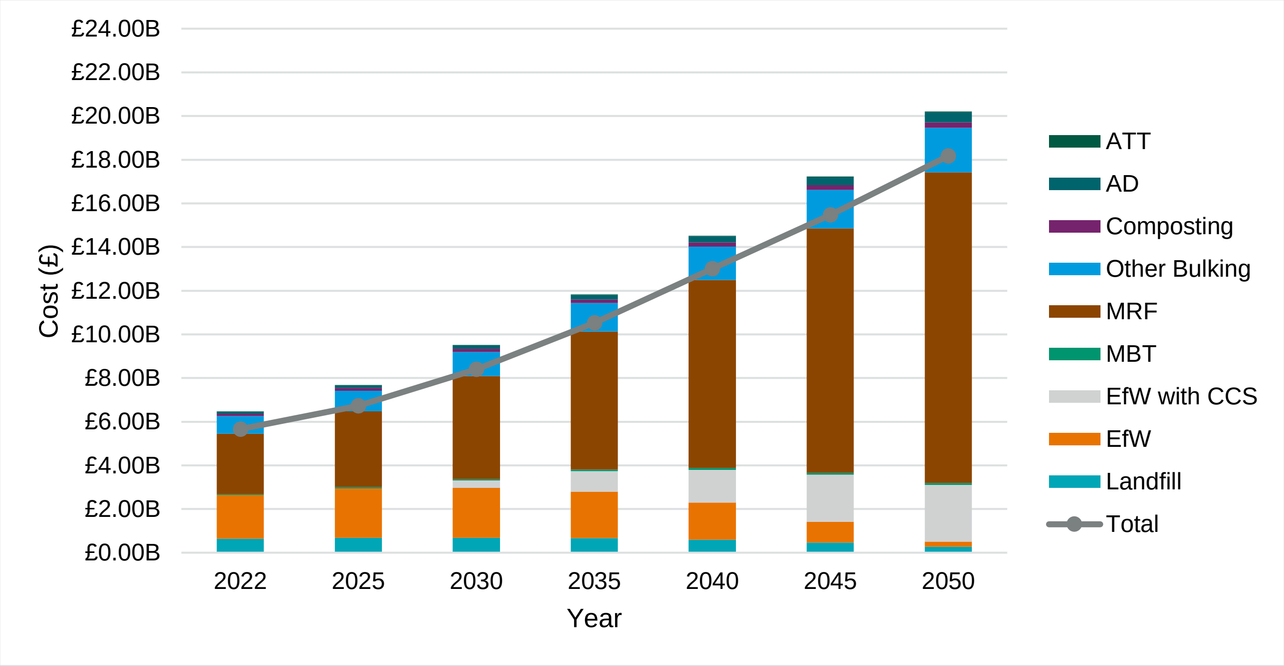


Figure 52: Scenario 1 (High Arisings – Medium Recycling) Cost per facility type (Capex + Opex)

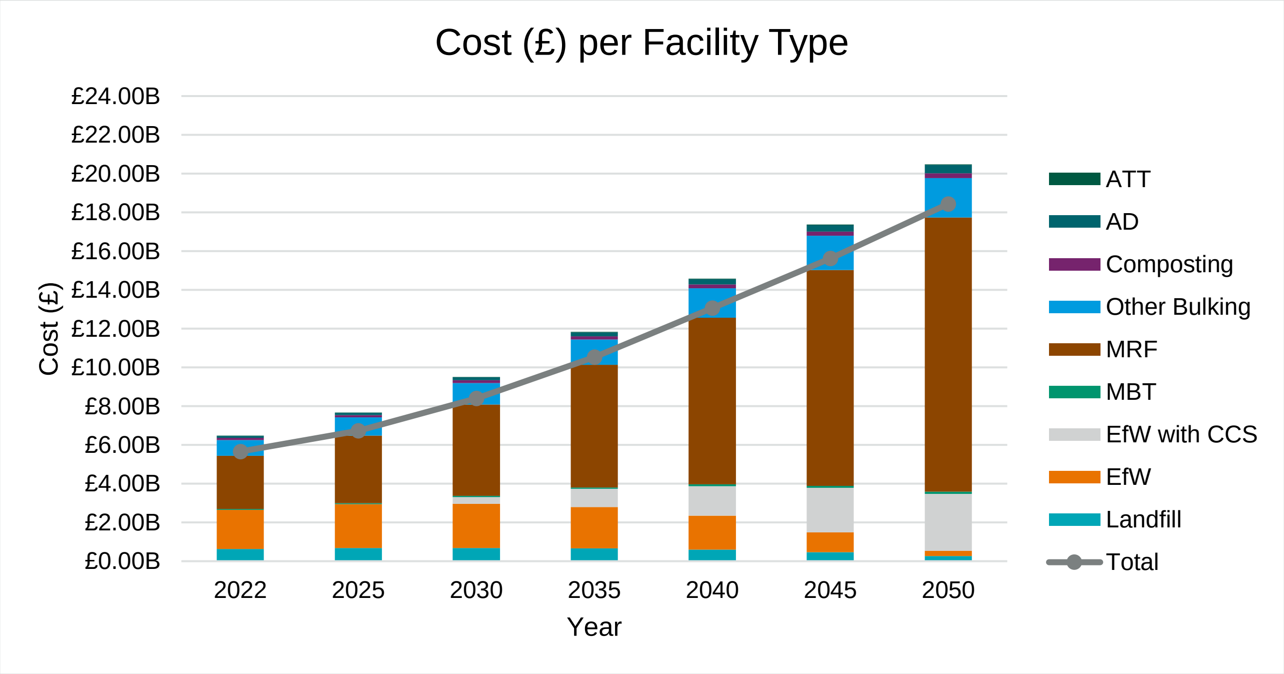
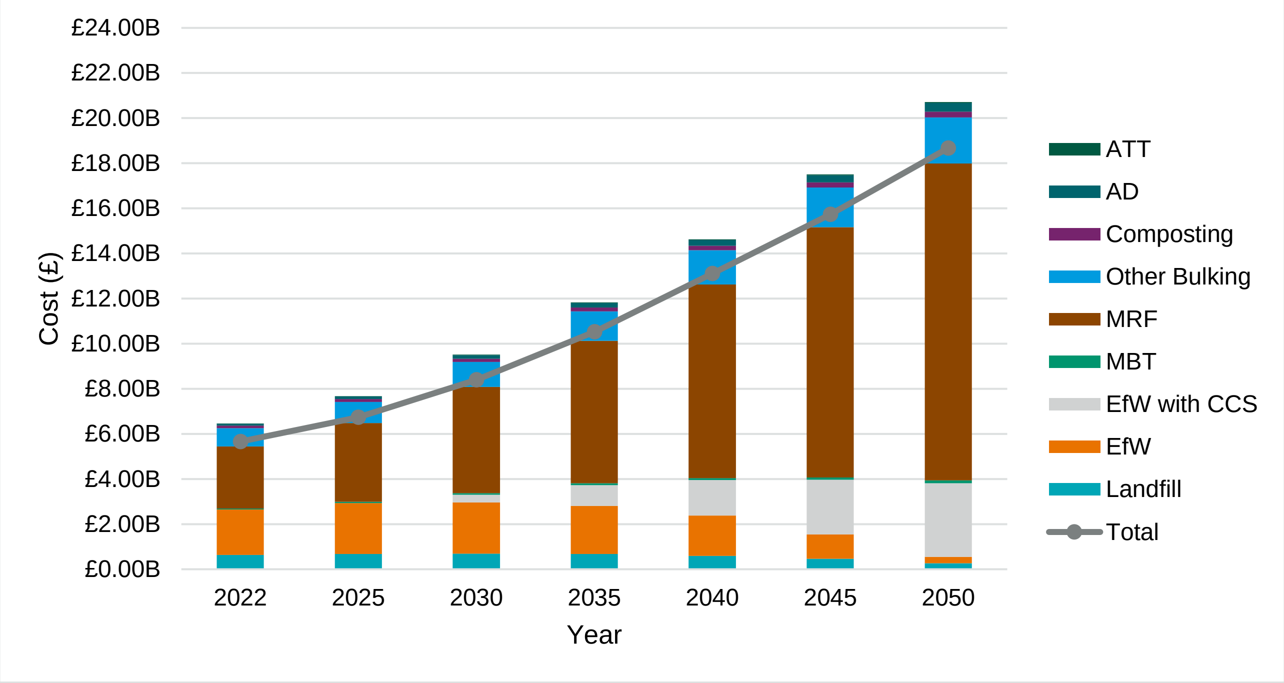


Figure 53: Scenario 1 (High Arisings – Low Recycling) Cost per facility type (Capex + Opex)



Scenario 2 results are presented in Figure 54 to Figure 56

Figure 54: Scenario 2 (Low Arisings – High Recycling) Cost per facility type (Capex + Opex)

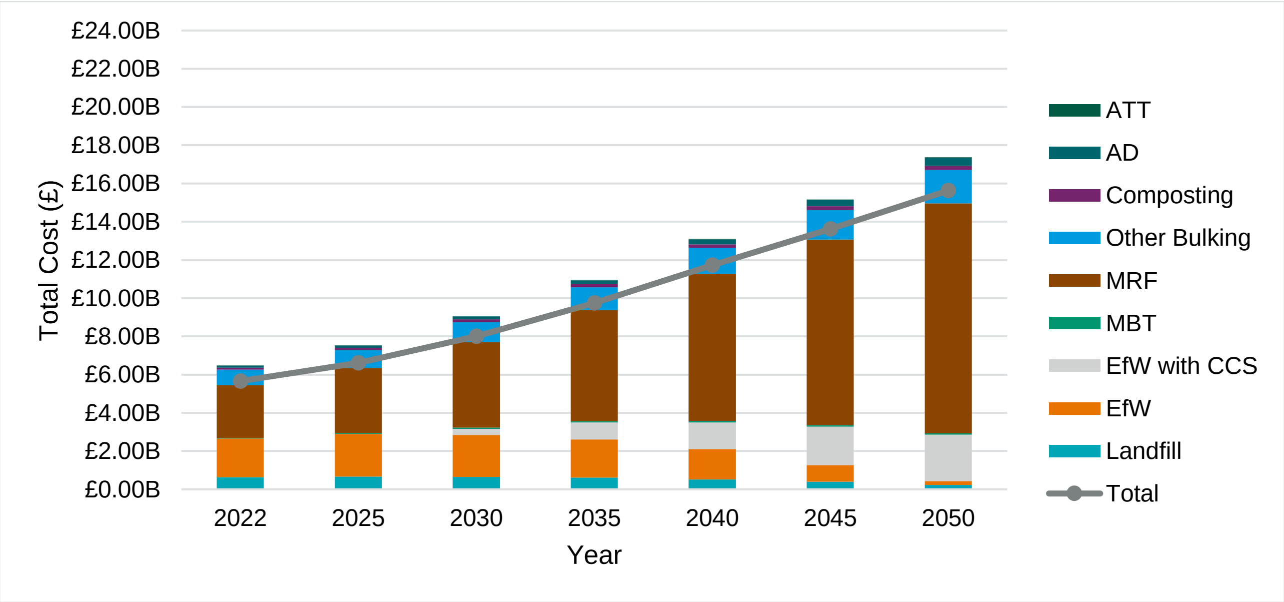


Figure 55: Scenario 2 (Low Arisings – Medium Recycling) Cost per facility type (Capex + Opex)

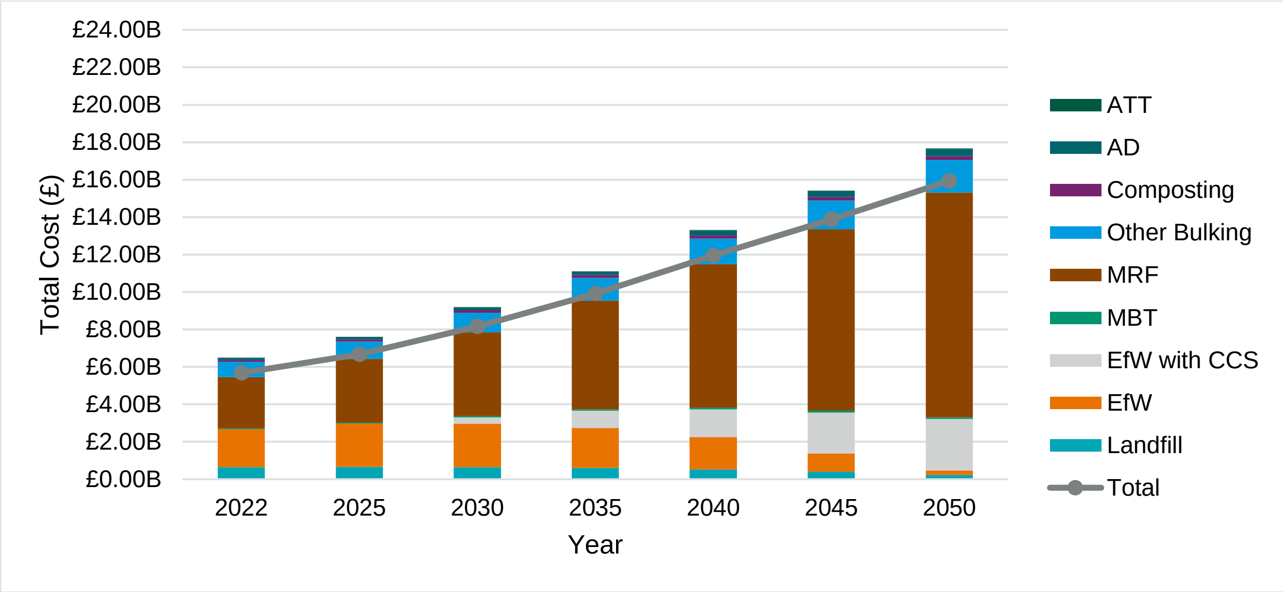
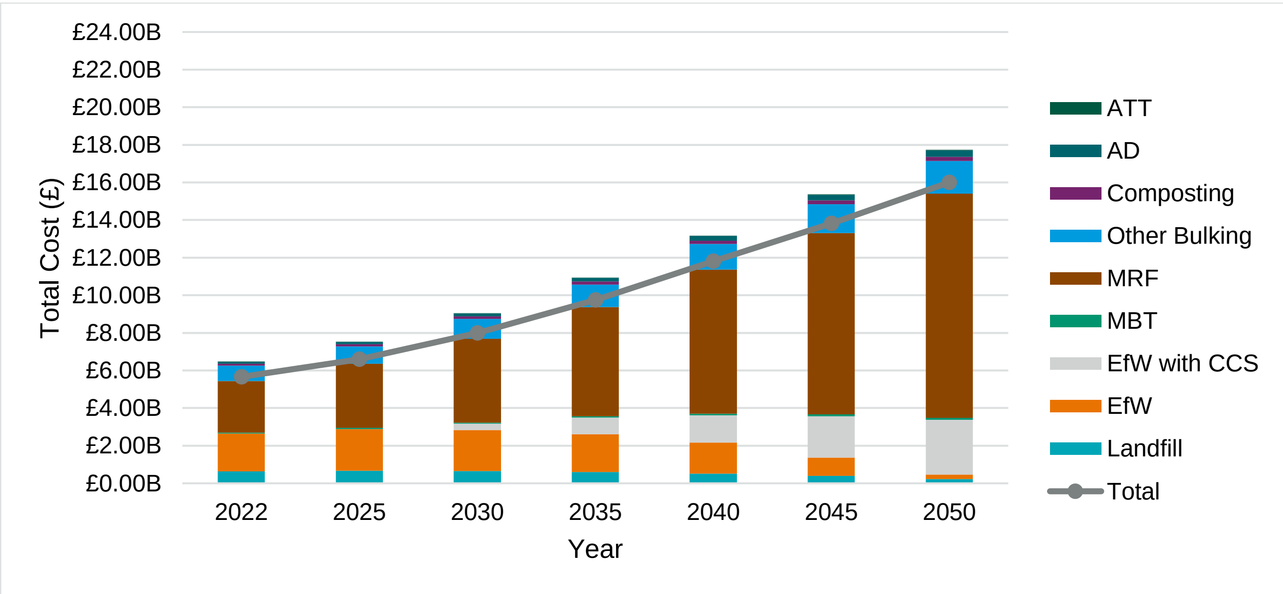


Figure 56: Scenario 2 (Low Arisings – Low Recycling) Cost per facility type (Capex + Opex)



Scenario 3 results are presented in Figure 57 to Figure 59

Figure 57: Scenario 3 (High Composition – High Recycling) Cost per facility type (Capex + Opex)

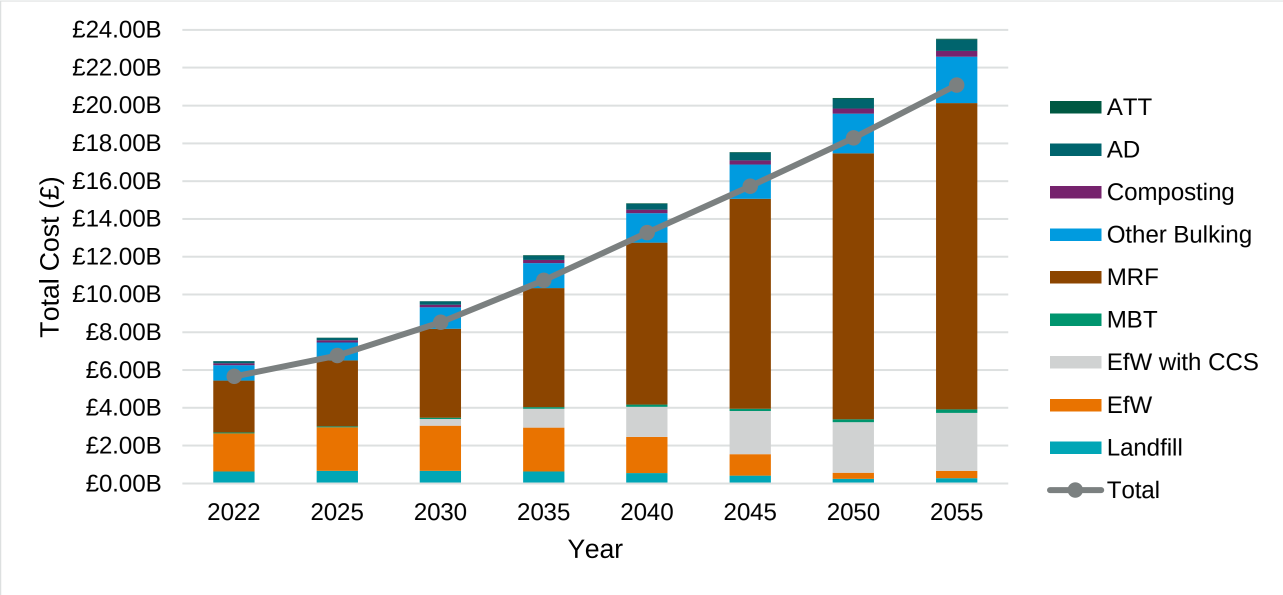


Figure 58: Scenario 3 (High Composition – Medium Recycling) Cost per facility type (Capex + Opex)

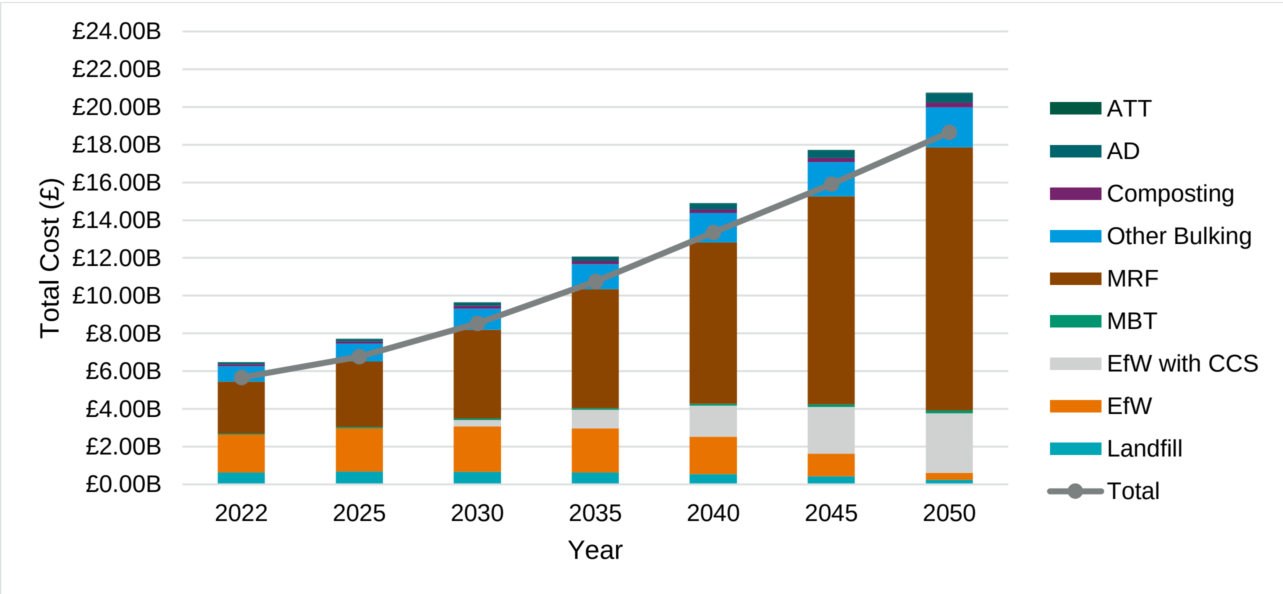
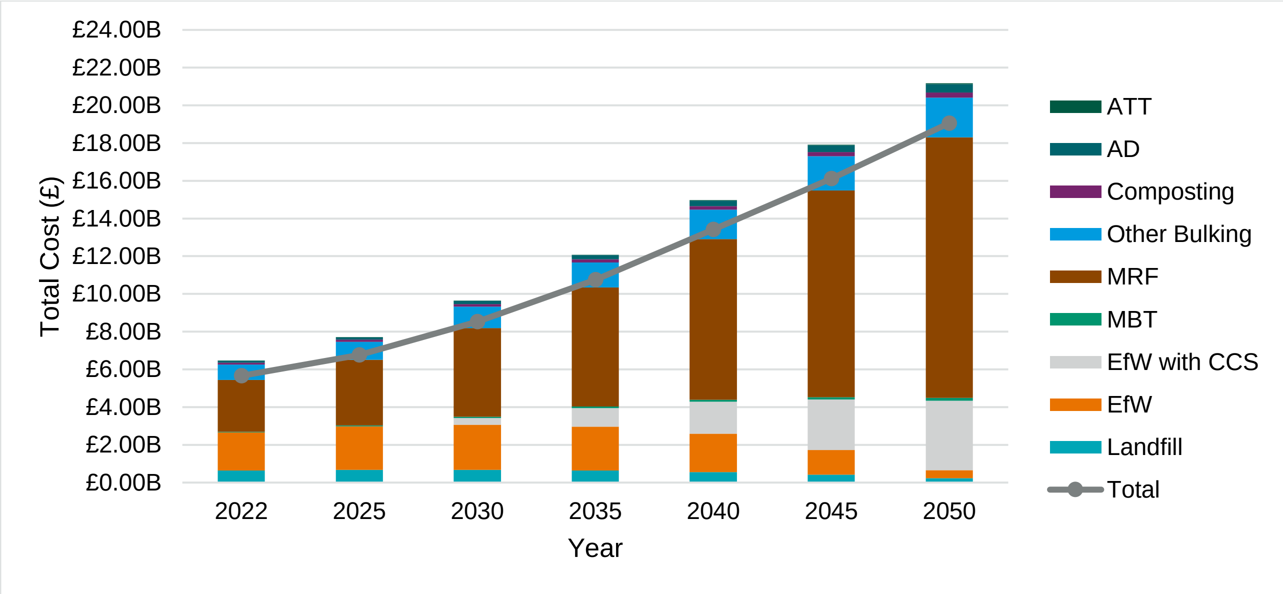


Figure 59: Scenario 3 (High Composition – Low Recycling) Cost per facility type (Capex + Opex)



Scenario 4 results are presented in Figure 60 to Figure 62

Figure 60: Scenario 4 (Low Composition – High Recycling) Cost per facility type (Capex + Opex)

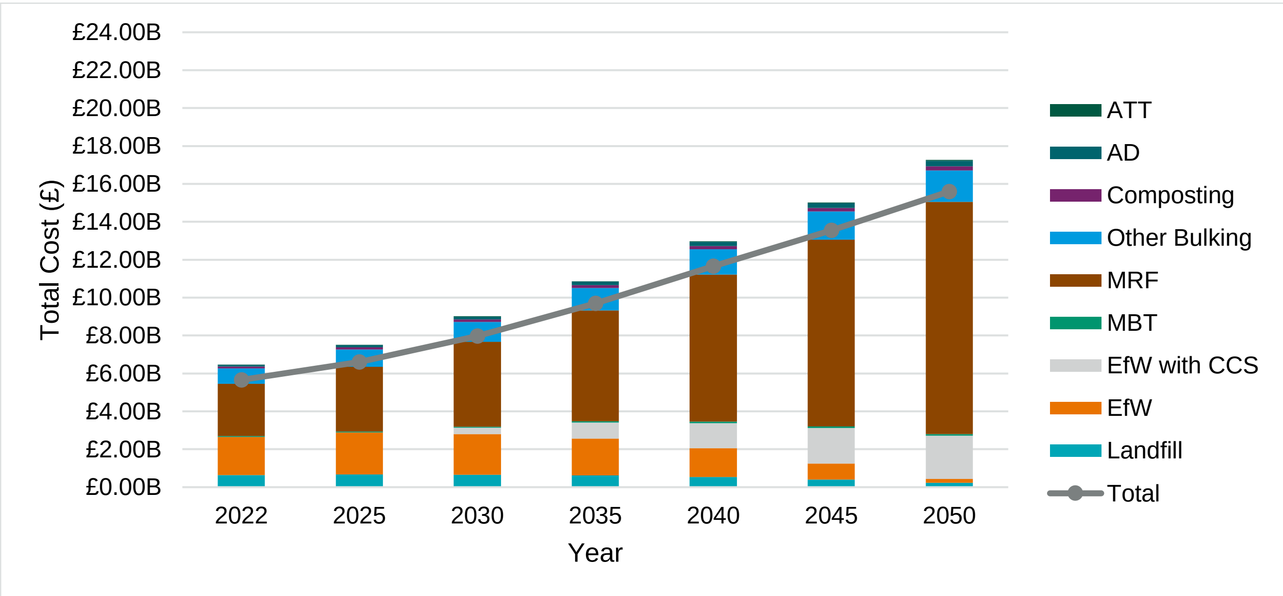


Figure 61: Scenario 4 (Low Composition – Medium Recycling) Cost per facility type (Capex + Opex)

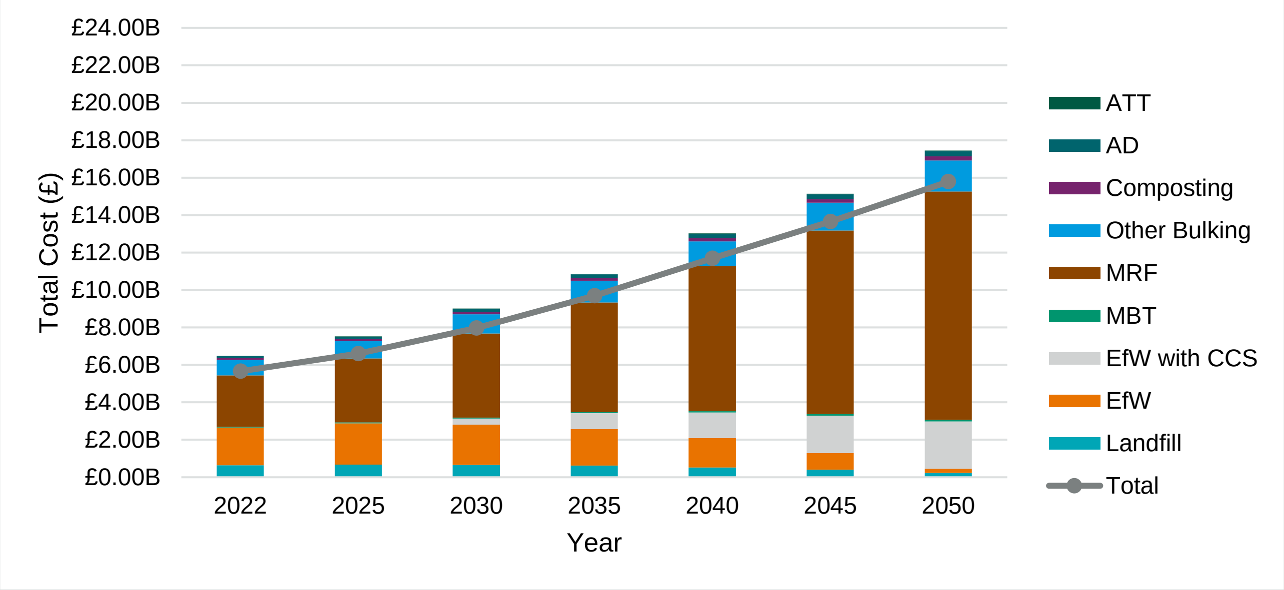
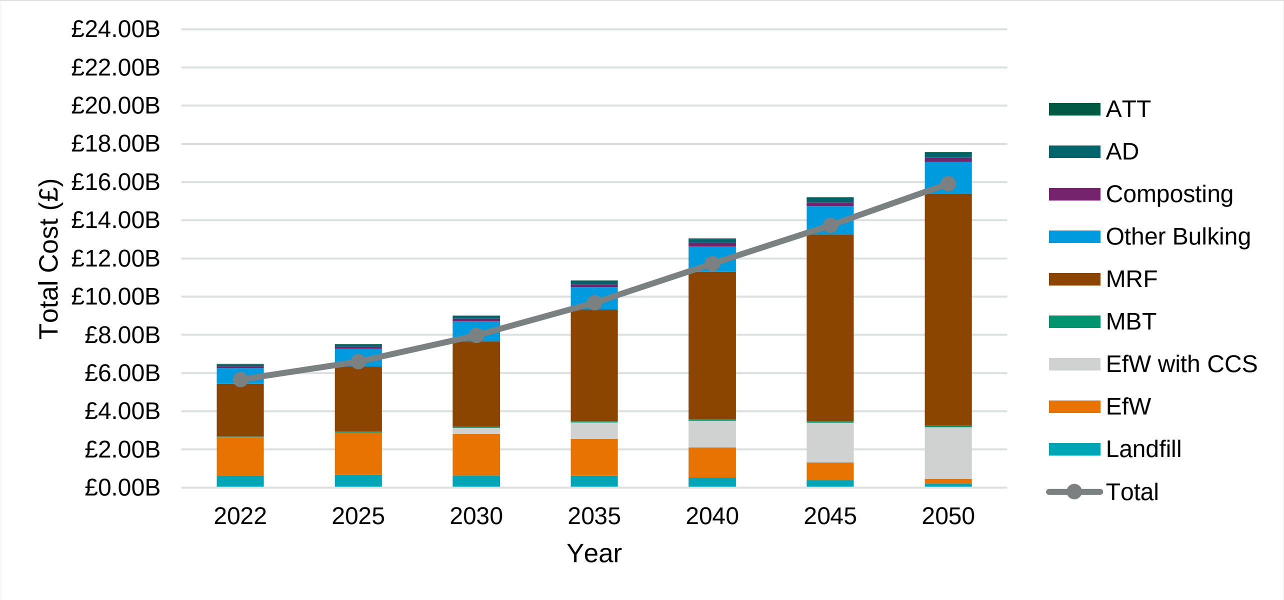


Figure 62: Scenario 4 (Low Composition – Low Recycling) Cost per facility type (Capex + Opex)



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